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Nitrification-Denitrification of Wastewater Using a Single-Sludge System

Volume I

Research Report No. 86

search Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

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POLLUTION CONTROL BRANCH

NITRIFICATION-DENITRIFICATION OF WASTEWATER USING A SINGLE-SLUDGE SYSTEM

VOLUME I

by

A.G. Smith
Ontario Ministry of the Environment

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
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ABSTRACT

Full-scale nitrification-denitrification of wastewater was conducted at the Newmarket, Ontario, Water Pollution Control Plant (WPCP), where primary stage lime treatment for phosphorus removal was being applied. The secondary treatment section was divided into two separate units, one for nitrification and the other for single-sludge nitrification-denitrification.

For nine months, fall to spring, the units were evaluated under ambient environmental conditions using, for the most part, on-site equipment. The object of this study was to see what degree of nitrification-denitrification could be maintained within a system with lime treatment. Experiments involved denitrification mixed liquor thickening, methanol dosing and supplementary iron salt addition for phosphorus removal.

Constant high (above 200 ml/g) sludge volume index (SVI) was experienced in both the nitrification and combined nitrification-denitrification units at Newmarket. This was thought to be caused by lime addition to the primary stage. Full nitrogen conversion and removal were disrupted by sludge chlorination for SVI control. Some limitations of the conventional facility were also found to affect nitrogen removal. Supplemental addition of ferrous sulphate, late in the program, to the aeration basin improved phosphorus removal and decreased SVI.

Subsequent pilot plant studies were carried out at Brampton and Kleinburg. In these a split-return mode of operation was evaluated under more controlled conditions. The requirements for methanol as a carbon source, process solids distribution, and post-aeration were evaluated for nitrification-denitrification under liquid temperatures ranging from 10 to 25°C.

More encouraging results were attained with the pilot unit. Denitrification solids thickening and thus improved nitrate removal was observed. Post-aeration proved necessary to maintain low effluent suspended solids, but did contribute dissolved oxygen to the denitrification tank contents.

RÉSUMÉ

Des expériences de nitrification et de dénitrification à l'échelle industrielle ont eu lieu à la station d'épuration de Newmarket en Ontario, où se pratique la déphosphatation primaire à la chaux. Le traitement secondaire s'est fait dans deux dispositifs distincts, l'un conçu pour uniquement nitrifier les boues et l'autre pour les nitrifier et les dénitrifier.

Durant neuf mois, de l'automne au printemps, on a mesuré le rendement de ces dispositifs dans des conditions typiques du milieu, à l'aide, la plupart du temps, du matériel dont on disposait sur place. Il l'agissait de déterminer dans quelle mesure on pouvait assurer la nitrification et la dénitrification des boues en aval du traitement à la chaux. Au cours des expériences, on a épaissi la liqueur mixte destinée à la dénitrification, ajouté une quantité détérminée de méthanol et une quantité supplémentaire de sels de fer pour retirer le phosphore.

L'indice du volume des boues (IVB) est demeuré élevé (supérieur à 200 ml/g) tant dans le dispositif de nitrification que dans celui de nitrification et de dénitrification combinées. L'addition de chaux au cours du traitement primaire en serait la cause. La chloration des boues pour stabiliser l'IVB a empêché la conversion totale des produits azotés et l'extraction de l'azote. Certaines contraintes inhérentes à ce type classique d'installation ont aussi nui à l'extraction de l'azote. Vers la fin du programme, l'addition d'une quantité supplémentaire de sulfate ferreux au bassin d'aération a amélioré la déphosphatation et abaissé l'IVB.

Des études pilotes subséquentes, menées à Brampton et à Kleinburg, ont permis d'évaluer le rendement de ce traitement de recirculation partielle des boues dans des conditions plus rigoureuses. Elles ont porté plus particulièrement sur les besoins en méthanol en tant que source de carbone, sur la répartition des matières solides et sur la post-aération pour nitrifier et dénitrifier des boues liquides à des températures variant entre 10° et 25°C.

Les résultats ainsi obtenus ont été plus encourageants. On a réalisé un épaississement des solides à dénitrifier et de ce fait une meilleure extraction des nitrates. La post-aération s'est révélée nécessaire au maintien du bas niveau de matières en suspension dans l'effluent, mais elle a contribué à faire augmenter la teneur en oxygène dissous dans le réservoir de dénitrification.

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CONCLUSIONS

1) The studies at Newmarket show the following:

   a) Lime addition to the primary stages may create conditions conducive to bulking activated sludge.

   b) Chlorination of return sludge for lowering SVI in a lime treated plant upsets nitrification reactions.

   c) A sludge return rate greater than 55% of the influent flow helps maintain nitrification and the recovery of nitrification reactions following a process upset.

   d) Consistent high nitrate removals are attainable only with good denitrification solids control.

   e) The on/off mixer operation in the denitrifcation basin did not provide solids thickening.

   f) Total phosphorus removal is offset by soluble phosphorus release in the denitrification basin.

2) The pilot plant studies at Brampton and Kleinburg have shown that:

   a) Nitrogen removals beyond the levels normally obtained in a conventional WPCP are attainable with the single-sludge system.

   b) The split-return arrangement is a viable method of controlling solids levels in the aeration and denitrification chambers.

   c) A separate post-aeration section is required to maintain clarifier suspended solids and BOD levels below 20 mg/L and prevent backmixing of aerobic mixed liquor into the denitrification basin.

   d) Depending on effluent nitrogen requirements and system detention time, methanol addition for denitrification may not be required at wastewater temperatures above 20°C.

   e) BOD/TKN ratio of the wastewater affects the denitrification reactions and ultimately the methanol requirements.

   f) Ferric chloride, while providing phosphorus removal, may also be useful in lowering SVI in the single-sludge system.

RECOMMENDATIONS

Based on studies at Newmarket, Brampton and Kleinburg, the following recommendations are made:

1) An evaluation of the single-sludge system for nitrification-denitrification without chemical addition for phosphorus removal under more controlled process conditions should be made.

2) Further investigations into the effects of primary stage lime addition upon the secondary biological process should be carried out.

3) The compatability of other chemicals such as ferrous and ferric salt and aluminum sulphate with the single-sludge system for nitrification-denitrification should be investigated.

4) Following pilot plant studies at Brampton and Kleinburg, a full-scale, single-sludge, split-return system should be evaluated under varying flow conditions and methanol requiremnts should be determined over an extended period.

ABSTRACT

Full-scale nitrification-denitrification of wastewater was conducted at the Newmarket, Ontario, Water Pollution Control Plant (WPCP), where primary stage lime treatment for phosphorus removal was being applied. The secondary treatment section was divided into two separate units, one for nitrification and the other for single-sludge nitrification-denitrification.

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Subsequent pilot plant studies were carried out at Brampton and Kleinburg. In these a split-return mode of operation was evaluated under more controlled conditions. The requirements for methanol as a carbon source, process solids distribution, and post-aeration were evaluated for nitrification-denitrification under liquid temperatures ranging from 10 to 25°C.

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devices. Secondary sludge recycle was directed to the anoxic zone (Figure 1 b)). This system produced nitrate reductions of 90% and total nitrogen removals of 85% at sewage temperatures of 13°C to 15°C. A more detailed evaluation of full-scale, single-sludge processes is given in a recent publication by the author [4].

1.3 Two-Sludge System

The two-sludge process as studied by Bringmann [5], and Johnson and Schroeffer [6] consists of separate clarifiers and sludge recycle systems for aeration and denitrification basins (Figure 1 c)). A primary effluent bypass to the denitrification basin is also used to provide an extra carbon source for denitrification reactions. The advantage of this system over the single-sludge process is that the aeration section can be operated at lower conventional solids levels; this, in turn, decreases the mixing and air requirements. The denitrification section can then be operated separately under optimum conditions for maximum nitrate removal. Data from these studies have shown that between 60 and 80% total nitrogen removal is attainable without methanol addition.

1.4 Three-Sludge System

The three-sludge system (Figure 1 d)) was developed by Barth and Etlinger [7] and pilot and full scale tested by Mulbarger [8] to improve the nitrification section of the process. By isolating the BOD_5 removal from the nitrogenous oxidation (NOD) functions, in separate controlled stages, more protection should be afforded the nitrification process from toxic wastes and cold weather [9]. The first stage is operated as a high rate process, accomplishing only minimal nitrification, followed by a nitrification stage in which complete oxidation of ammonia is attempted prior to denitrification. Methanol addition is normally required to produce full (more than 90%) denitrification at a minimum dosage of three parts methanol to one part of nitrate-nitrogen.

1.5 Effects of Chemical Phosphorus Removal on Biological Nitrogen Removal

Since both phosphorus and nitrogen removal may be required simultaneously in some communities, the phosphorus removal chemicals would have to be compatible with nitrification and/or denitrification processes.

Investigations at the University of Toronto by Kitay [10] on the effects of phosphorus precipitants on nitrifying activated sludge produced some interesting comparisons of the action of lime, aluminum sulphate and ferric chloride. It was found that as much as 60% and 100% nitrification inhibition was caused by equal dosages of 200 mg/L of $Al_2(SO_4)_3$ and $FeCl_3$, respectively, over 13 days. At similiar addition levels, nitrification was enhanced by the application of CaO when a pH of 8.0-9.0 was maintained in the aeration mixed liquor. Decreased nitrification with lime dosing was indicated only when the mixed liquor pH rose above 9.0.

These observations by Kitay on lime addition further substantiate findings by Black [11] at the Newmarket nutrient removal facility. In this study, consistent full nitrification was being accomplished with two of the three previously used aeration chambers. This was believed to be the result of raised aeration mixed liquor pH (to 8.5) and lowered food to microorganism (F/M) ratios due to the primary lime treatment stage.

Using a cycled aerobic-anaerobic, single-sludge system, Bishop et al [12] experimented with and without ferric chloride in the primary stage for phosphorus removal. Overall nitrogen removal with this process without iron addition ranged from 75 to 84% at wastewater temperatures of 15° and 25°C, respectively.

During two months of ferric ion addition, the total nitrogen removal efficiency dropped to 67% while phosphorus removal rose from a low of 25 to 85%. The loss in nitrogen removal during primary stage ferric ion addition was attributed to a lowering of primary effluent chemical oxygen demand to total Kjeldahl nitrogen (COD/TKN) ratio. The COD/TKN ratio dropped from 10:1 to between 7 and 8:1.

1.6 Choice of Process and Study Format

The conventional single-sludge process arrangement was chosen for evaluation in this study because it was thought to be more adaptable to existing activated sludge facilities. The major drawbacks of the multi-stage systems are that the additional clarifiers and return sludge equipment which must be provided add complexity and expense to an installation. The advantages and disadvantages are futher discussed by the author [13] in a publication on design of nitrification plants.

With the single-sludge arrangement, full-scale nitrification-denitrification studies were first conducted at the Newmarket WPCP, which at that time was using lime treatment for phosphorus removal. The evaluation at Newmarket was terminated when the inadequacies of the facility for a fair evaluation of the nitrogen removal process were realized. A portable pilot plant was then designed and tested at the Brampton, Ontario Experimental Facility and the Kleinburg WPCP, under more controlled process conditions.

This report presents the information derived from the full scale studies at Newmarket and the pilot plant tests at Kleinburg and Brampton, conducted between October, 1972 and June, 1974.

2 OVERALL OBJECTIVES

The purpose of the studies reported here was to investigate the efficiency of the single-sludge system for nitrification-denitrification of domestic wastewater under prevailing Ontario climatic conditions.

The following aspects were of particular interest:

(a) The adaptability of this sytem to conventional activated sludge plants and its ease of operation.

(b) The effects of wastewater temperature and other parameters on nitrification and denitrification reactions.

(c) Methanol requirements for denitrification as related to solids concentrations, detention time and temperature.

(d) Effects of chemical additions for phosphorus removal on nitrification and denitrification reactions.

(e) To assess various methods of sludge thickening for denitrification under continuous and variable flow conditions.

3 NEWMARKET STUDY

3.1 Specific Objectives

The aims of the Newmarket evaluation were to test the single-sludge system for nitrification-denitrification using a conventional WPCP facility. The effects of the primary stage lime addition for phosphorus removal, secondary system solids control, and methanol requirements at varying wastewater temperatures were of prime interest.

3.2 Description of the Project Facilities

The Newmarket sewage treatment plant is a conventional activated sludge plant with two-stage anaerobic digestion. Daily flows of mainly domestic sewage average 1.8 Imgd (8181 m^3/day). The raw sewage is treated with hydrated lime at 200 mg/L in a flash mixer. Subsequently, the lime-sewage mixture receives primary sedimentation followed by mechanical aeration, final settling and chlorination.

Alterations for biological nitrogen removal studies were made to part of the existing Newmarket plant facilities during September, 1972. The lowered BOD loading to the aeration chambers, due to the primary lime addition, made it possible to delete one aeration section from the process. This section was converted to a denitrification unit by connecting a 12-inch pipe from a point near the exit of the adjacent aeration chamber to the head of the spare basin. The mechanical aerators were converted to mixers by replacing the aerator blades with a shaft and propeller. (See Figure 2 and Photographs 1 and 2).

Flow to two final clarifiers was separated by adjusting existing influent channel gates and valves. Sludge return was separated at a common clarifier drawoff well by inserting a flexible section line of a 300 Igpm centrifugal pump down one of the adjustable slip-tubes. The return sludge pump then discharged through 200 ft. of pipe to the influent end of both aeration and denitrification basins, where the option of splitting the flows was provided by valves. These alterations separated the Newmarket WPCP into two secondary treatment sections: a control or nitrification unit, and a N-removal unit of single-sludge nitrification-denitrification mode.

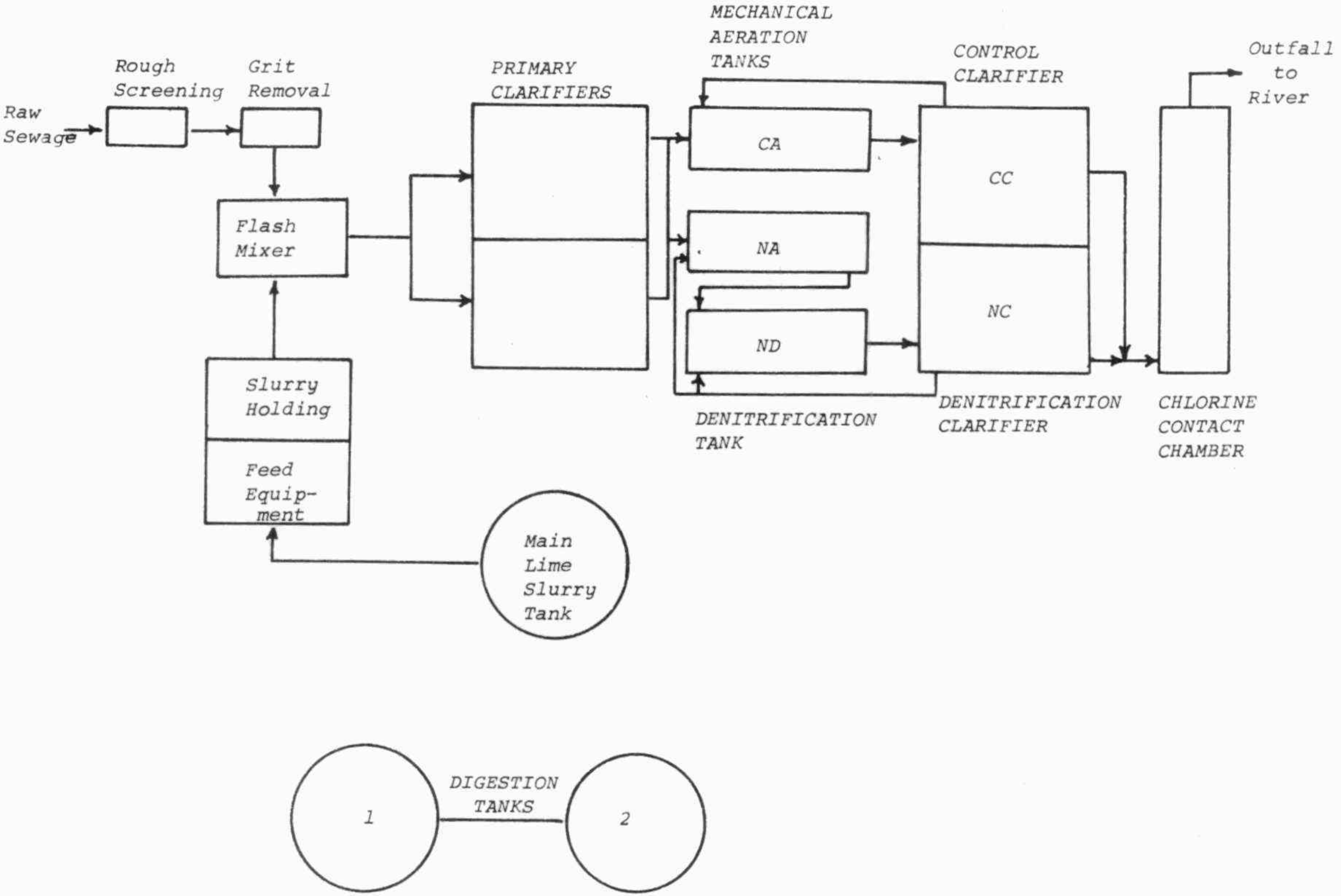
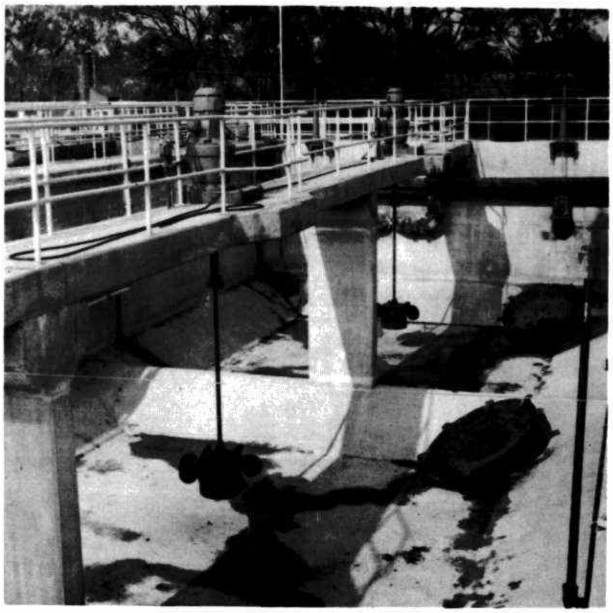


FIGURE 2. NEWMARKET WPCP FLOW DIAGRAM



PHOTOGRAPH 1. AERATORS CONVERTED TO MIXERS

PHOTOGRAPH 2. INSTALLED DENITRIFICATION TANK INFLUENT PIPE

The primary effluent flow to the N-removal unit was kept at 0.8 Imgd (3636 m^3/day) by maintaining a constant aeration liquid level over the 12" discharge opening. Additional flow control was provided at both aeration basin inlets via Parshall flumes and gate control. The control unit received flows in excess of that accepted by the N-removal unit, up to a maximum of 1.2 Imgd (5455 m^3/day). When flows exceeded 2.0 Imgd (9,100 m^3/day), as during storm periods, primary effluent was bypassed to the chlorine contact chamber.

Gentle air stripping was provided to the last ten feet of the denitrification tank to strip the sludge of nitrogen and carbon dioxide gases before it entered the final clarifier. The air delivery to this section was 18 cu ft/gal/hr (0.11 cu m/L/hr). At flows of 1.2 and 0.8 Imgd, for the control and N-removal units, respectively, the following operational parameters for unit components were obtained:

Basin Detention Time (hours without recycle)	
Aeration (Control)	5.0
Aeration (N-removal)	7.4
Denitrification	6.7
Post-aeration	0.45

Clarifier Overflow Rates - gal/ft^2/d (m^3/m^2/d)	
Primary	1000 (49)
Final (Control)	820 (40)
Final (N-removal)	655 (32)

Average Flow - Imgd (m^3/d) x 10^3

November	2.07 (9.4)	March	1.85 (8.4)
December	1.65 (7.5)	April	1.86 (8.5)
January	2.01 (9.1)	May	1.65 (7.5)
February	1.58 (7.2)	Average	1.81 (8.2)

3.2.1 Sampling and analyses

For the most part, the following procedures were applied to the Newmarket study:

i) Twenty-four hour composite samples were taken of raw sewage, primary and final effluents.

ii) Composite grab samples of aeration and denitrification mixed liquors were taken and filtrates obtained for dissolved chemical analyses.

iii) On-site filtrates were also taken from raw sewage, primary and final composites to ensure the stability of soluble components for analyses later.

iv) On-site tests consisted of measurements of half-hour settling rates on all mixed liquors, respiration rates, pH, ammonia and batch nitrification and denitrification rates. Nitrate analyses for process control were performed on-site with a specific ion electrode and meter. This method of nitrate measurement was evaluated for process control purposes by comparing instrument standardization with sodium nitrate with and without chloride, and also using final effluent with a known concentration of nitrate nitrogen.

v) Composite samples were taken to the Ministry's Central Laboratory daily for comprehensive chemical analyses. Chemical analyses performed on composite samples were: biochemical oxygen demand (BOD), suspended solids (SS), total and soluble phosphorus, total kjeldahl nitrogen (TKN), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N), total organic carbon (TOC), chemical oxygen demand (COD) and alkalinity. Mixed liquors were analyzed for suspended and volatile solids and alkalinity. Mixed liquor filtrates were analyzed for phosphorus, ammonia, nitrite, nitrate, TOC and alkalinity.

All analyses were performed in accordance with the procedures outlined in Standard Methods for the Analysis of Water and Wastewater, American Public Health Association, 13th edition, 1971.

3.2.2 Experimental design

In setting up the study, the intent was to operate the N-removal unit under various conditions to determine the effects of such variables as solids concentration, methanol addition and wastewater temperature on nitrification and denitrificaiton rates and efficiencies. The control unit was to be operated in the conventional mode for comparitive purposes.

During the course of the project, however, various conditions which required alteration of the study plan emerged. The study was plagued with process upsets due to the prolific growth of the filamentous bacteria in both units. Thus, on occasion, chlorination of the return sludge streams was carried out for filamentous bacteria control. Towards the end of the study, additons of ferrous sulphate were made to both units to improve phosphorus removal efficiencies and to determine effects of such additions on secondary sedimentation.

Because of the differences found during the course of the study in the nitrification performance between the control and N-removal units, three sets of batch nitrification rate tests using aeration mixed liquor were conducted on site. These tests consisted of aerating various proportions of primary effluent, aeration mixed liquor and return sludge in an insulated 5 gal (23 L) container for six hours. Analyses for soluble nitrogens were performed at regular intervals throughout the six-hour test period, thus a nitrification rate was attained for each batch.

Series 1 of the batch tests was run during March to determine the effect of increasing the temperature of the N-removal aeration mixed liquor on nitrification rate.

Series 11 batch tests were conducted to determine if any improvement in nitrification rate could be achieved by inoculating the N-removal plant aeration mixed liquor with the control plant sludge.

Series 111 tests were conducted to simulate effects of a higher rate of sludge return and the N-removal aeration basin.

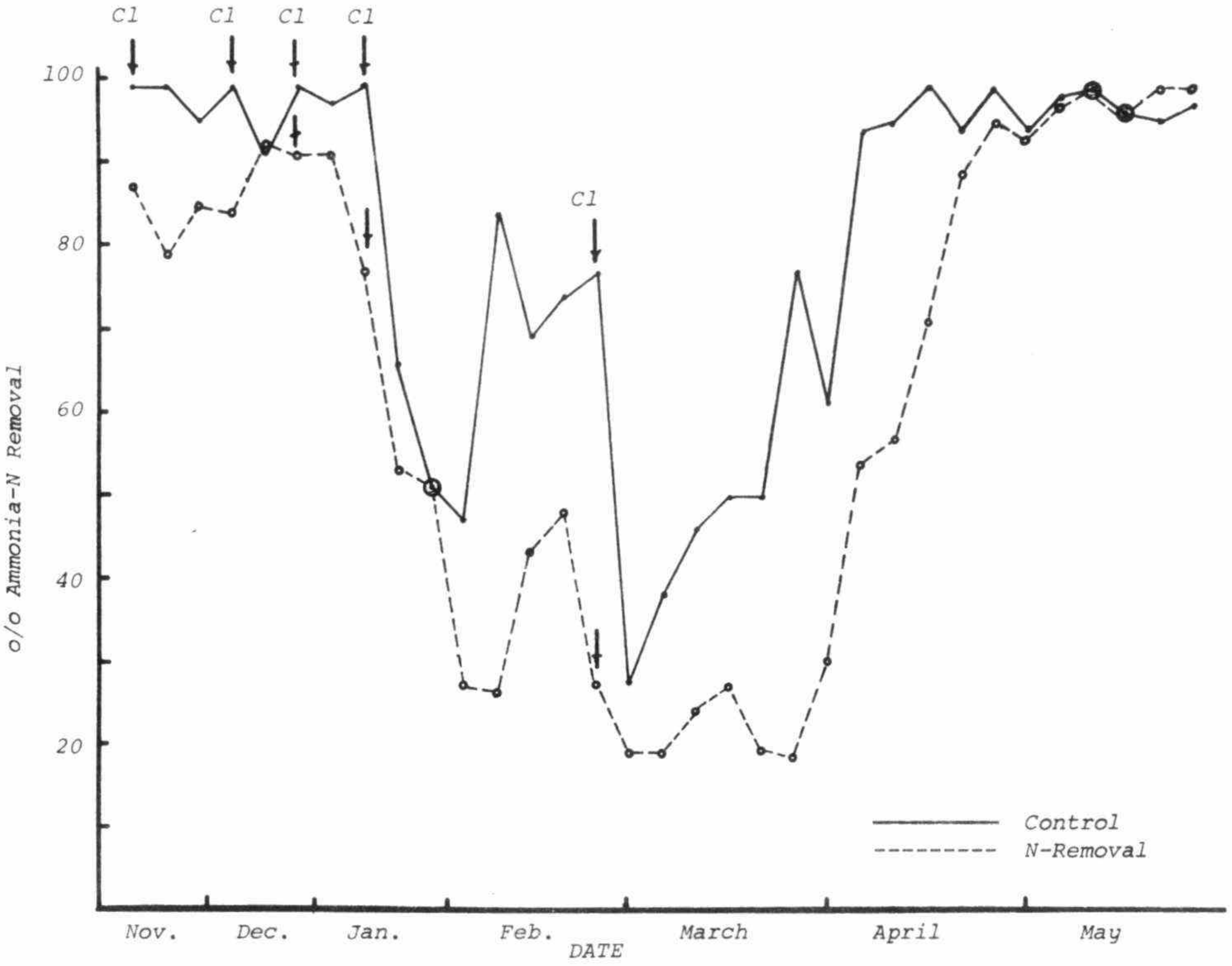
To supplement the denitrification basin reactions, methanol was added at methanol-to-nitrate ratios of 1:1 and 3:1. The additions were made at various times during the course of the study to provide a soluble carbon source for the denitrifying bacteria. Periods of non-addition were interspersed between periods of addition for comparative purposes. Increased denitrification sludge volume index (SVI) and resultant deterioration in secondary sedimentation, with methanol addition, occasionally necessitated non-addition. This was done to prevent a loss of process solids due to clarifier bulking at peak flows.

Previous reactor studies [1] had shown that rate of denitrification increases when mixed liquor suspended solids levels are raised from 2,000 to 5,000 mg/L. Consequently, attempts were made, under full-scale conditions, to increase the suspended solids level within the denitrification basin to reduce the quantity of methanol required. Denitrification mixed liquor thickening was attempted by diverting up to one-half of the return sludge to the head of the denitrification basin. Another method tried was to maintain full sludge return to the aeration basin, but to allow the denitrification basin mixed liquor to settle for 30 minutes out of each hour. This was accomplished by electrically controlling the on-off time of the denitrification mixers.

3.3 Results

3.3.1 Full-scale nitrification

A high level of ammonia oxidation (nitrification) was maintained in both the control and the N-removal units during the first two months of the study (November and December). As shown in Figure 3, nitrification efficiencies in both units dropped sharply in January when chlorination of the process return sludge for filamentous organisms control was implemented. Some recovery in nitrification was seen in February with the control plant exhibiting better results. A second chlorination was required in late February to counteract bulking sludges in both plants and nitrification was again disrupted and had not fully recovered until March in the control and April in the N-removal unit.



	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
MEAN MONTHLY SEWAGE TEMP. ^{o}C	12.5	10.5	8.0	8.0	9.0	10.0	13.0
TOTAL SLUDGE AGE (days) C	2.4	3.5	2.3	4.0	1.5	3.3	3.3
TOTAL SLUDGE AGE (days) N	3.0	4.4	3.1	4.9	3.5	4.2	6.7

FIGURE 3. COMPARISON OF NITRIFICATION EFFICIENCY OF NEWMARKET PROCESSES

Consistently better nitrification recovery occurred in the control plant following chlorination even though the total process sludge age* was lower (Figure 3).

Figures 4 and 5 provide a comparison of the performance of the aeration basins of the two plants. More ammonia was being oxidized per weight of aeration volatile suspended solids (VSS) in the N-removal unit, early in the study. This trend reversed following the addition of chlorine to both plants and the ammonia oxidized per weight of VSS subsequently remained higher in the control unit aeration.

The oxygen uptake rates, based on VSS content of both aeration basins (mg O_2/hr/g VSS) (Figures 4 and 5), show parallel changes with specific nitrification rate. Absolute specific uptake rate (SUR) values did not correlate closely with resultant nitrification rate but, in most cases, changes in direction of each were similar.

3.3.2 Nitrification batch tests

(a) Series 1

During March the control and N-removal aeration basins were producing nitrification efficiencies of 51 and 21% respectively, at a mean mixed liquor (M.L.) temperature of 9°C. Under batch test conditions, (see section 3.2.2), no ammonia oxidation took place at M.L. temperatures between 9 and 13°C (Table 1). Some nitrification took place in batches at 17.5 and 21.7°C at similar M.L. pH. Moreover, the improved nitrification seen at the higher temperature levels coincided with raised M.L. SUR.

(b) Series 11

In April, the control unit aeration was continuing to produce better nitrification than was the N-removal unit. Batch tests at this time showed little or no improvement in nitrification rate at similar

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$$\text{*Total Sludge Age [14]} = \frac{\text{Total Solids in Aeration and Denitrification Chambers}}{\text{Total Solids added/day}}$$

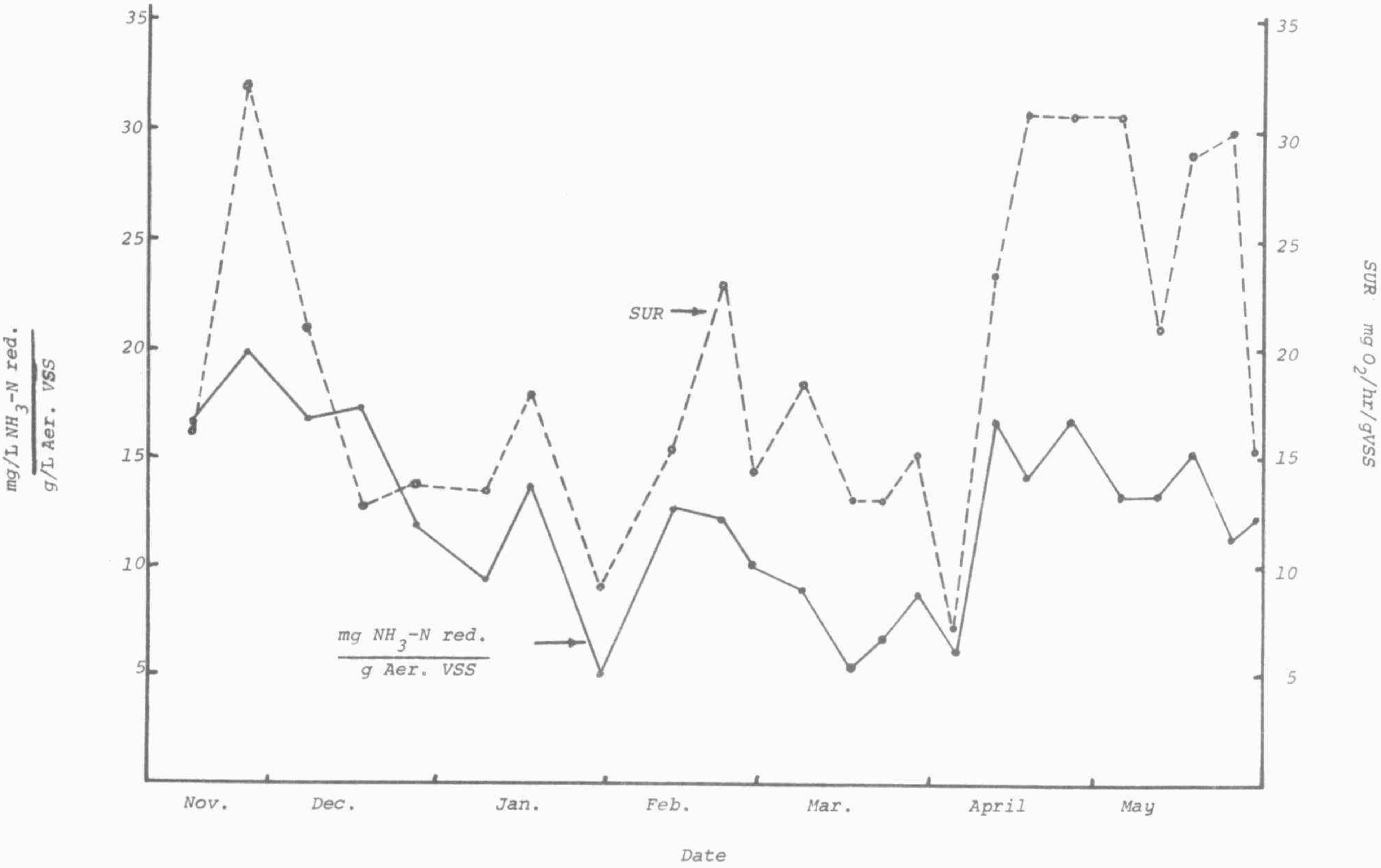


FIGURE 4. COMPARISON OF AMMONIA OXIDIZED AND SPECIFIC UPTAKE RATE (CONTROL AERATION)

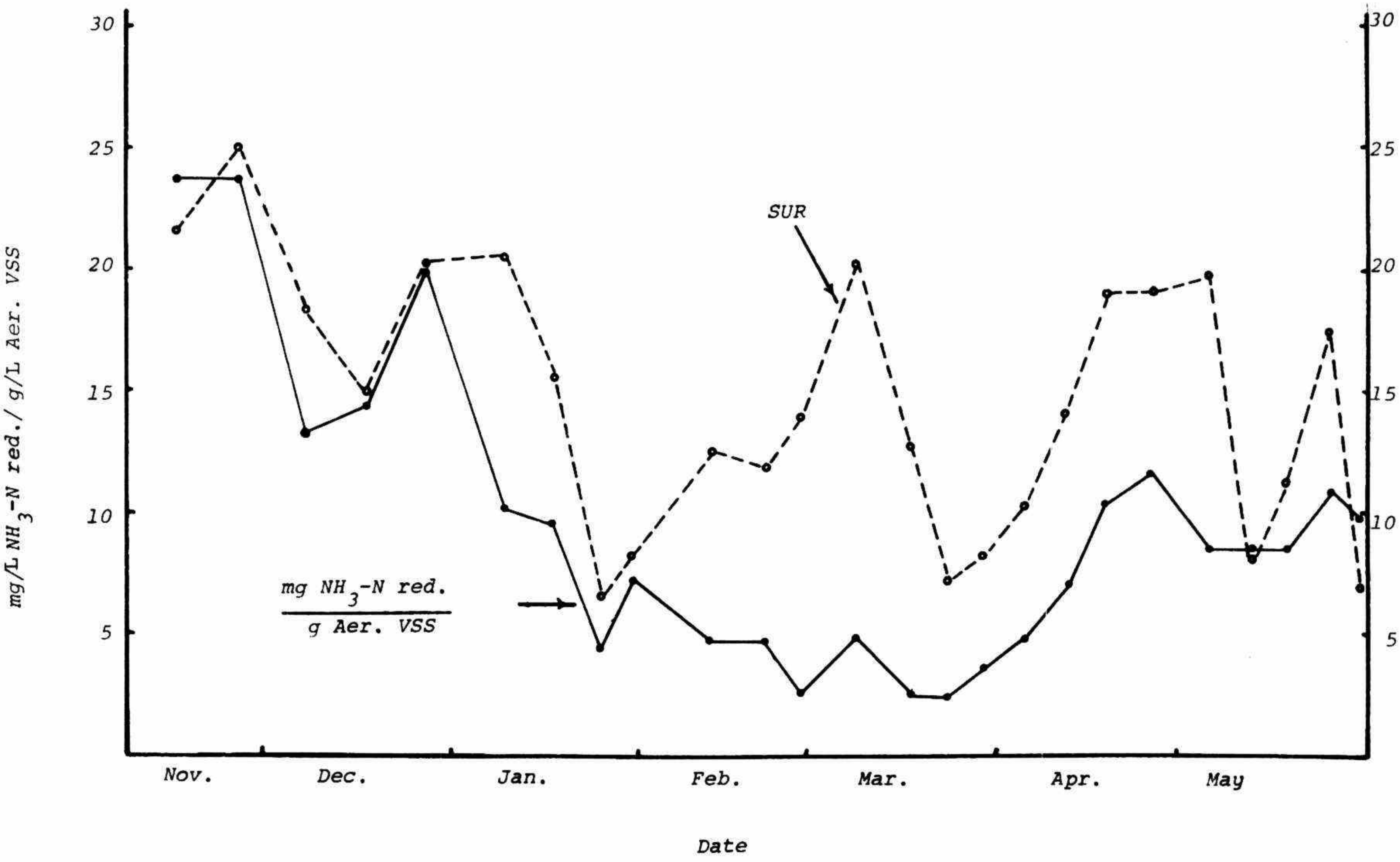


FIGURE 5. COMPARISON OF AMMONIA OXIDIZED AND SPECIFIC UPTAKE RATE (N-REMOVAL AERATION)

M.L. pH and temperature during inoculation of the N-removal aeration with control unit return sludge (Table 1).

(c) Series 111

When the N-removal unit sludges only were worked with, a marked improvement in nitrification was realized on increasing the proportion of N-removal return sludge in the tests. At similar temperature and pH, the oxidation of ammonia almost doubled, comparing phases (A) and (B); however, a drop in M.L. SUR occurred.

3.3.3 Denitrification results

(a) Attempts at sludge thickening. Attempts to achieve mixed liquor thickening in the denitrification basin, produced only minimal effects. As seen in Table 2, only a slight rise in suspended solids was produced in the denitrification chamber over the N-removal aeration, by splitting the sludge return. Maximum solids thickening was achieved in the denitrification basin when the return sludge portion to that area was higher. This, in turn, caused a solids drop in the N-removal aeration to a point where maintenance of a low F/M ratio was difficult. Often this would happen within 24 hours, and necessitate reverting to an equal return split between the two basins.

The timed on-off sequence for the denitrification mixers also proved ineffective for sludge thickening. A noticeable drop in return sludge concentration occurred during these test periods with little or no difference seen between aeration and denitrification basin solids levels. (See January, Table 2.)

Generally, thickening attempts were further impeded by solids loss to the secondary effluent during peak flow periods. Frequent high denitrification SVI (Table 2) adversely affected clarifier sedimentation during the winter months.

(b) Effect of methanol addition and temperature. N-removal data comparing methanol addition with non-addition segments of the study are presented in Table 3, along with temperature and 0_2 uptake rate. Generally, nitrate reductions were improved by raising the methanol to nitrate N ratio from 1:1 to 3:1. These

TABLE 1. SIX-HOUR NITRIFICATION BATCH TEST RESULTS

Test Series	Mixture Proportions
1	½ part prim. effl:-¼ part N-removal-aer.:-¼ part N-removal-return
11(A)	½ part prim. effl:-¼ part N-removal-aer.:-¼ part N-removal-return
(B)	½ part prim. effl:-¼ part N-removal-aer.:-¼ part control-return
111(A)	¼ part prim. effl:-¼ part N-removal-aer.:-½ part N-removal-return
(B)	1/6 part prim. effl:1/6 part N-removal-aer.:2/3 part N-removal-return

MEAN VALUES

Series	ML T°C	ML SUR mg O_2/hr/g VSS	mg NH_3-N oxidized	M.L. pH
1	9.1	0.78	0	8.3
	9.4	1.04	0	8.3
	10.3	1.12	0	8.5
	13.0	1.70	0	8.3
	17.5	2.18	2.3	8.6
	21.7	1.91	3.0	8.4
11(A)	11.6	1.35	6.0	7.8
(B)	11.4	1.23	7.5	7.4
111(A)	12.6	1.24	9.0	8.1
(B)	12.5	0.90	16.0	8.1

TABLE 2. NEWMARKET MEAN MONTHLY ANALYTICAL RESULTS

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY
Raw Sewage (mg/L)							
BOD	-	-	197	191	168	144	190
SS	-	-	331	283	395	292	377
NH_3-N	-	-	23	26.6	16.5	15.0	20.5
TKN	-	-	38	48.3	33.6	29.0	39
Total P	-	-	5.9	12.3	10.3	7.9	8.9
Soluble P	-	-	3.4	5.3	3.4	3.1	4
Primary Effluent							
BOD	60.6	60.5	105.8	102	77.0	61	80
SS	107.0	93.1	128.5	92.3	104.3	106	98
NH_3-N	19.6	18.5	13.7	22.0	12.9	14	18
TKN	31.8	30.0	22.4	35.0	22.0	22	27
Total P	3.7	3.5	3.1	5.4	4.2	4.0	3.7
Soluble P	1.4	1.0	1.2	2.3	1.6	1.6	1.2
Control Aeration							
SS (mg/L)	1422	2062	1709	1959	1975	1920	1763
VSS (mg/L)	1075	1530	1076	1439	1077	1047	1243
SVI (ml/g)	298	270	185	353	87	146	187
O_2 Used (mg/L/hr)	21	19	15	17	15	22	33
N-Removal Aeration							
SS (mg/L)	942	1760	1679	1833	1433	2070	2798
VSS (mg/L)	713	1317	1133	1340	779	1145	1880
SVI (ml/g)	224	271	175	247	94	83	134
O_2 Used (mg/L/hr)	26	19	10	14	10	18	22
Denitrification							
SS (mg/L)	1392	1275	1735	2256	1840	2100	2895
VSS (mg/L)	1040	1239	1207	1903	1023	1162	1921
SVI (ml/g)	371	338	266	270	101	90	144
O_2 Used (mg/L/hr)	20	12	6	14	13	16	25

TABLE 2. (cont'd)

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY
Control Clarifier (mg/L)							
BOD	7.9	12.4	19.2	64.5	27.5	12.0	18.0
SS	20.7	17.1	17.3	51.8	12.5	7.0	9.0
TKN	2.8	2.5	5.5	16.5	8.5	2.0	2.2
NH_3-N	0.37	0.6	3.2	9.4	6.6	0.6	0.5
NO_2-N	1.04	2.7	0.4	0.6	0.9	0.4	0.6
NO_3-N	17.5	13.3	12.0	9.2	7.2	13.0	15.0
Total P	2.9	2.8	2.3	4.8	1.3	1.9	1.6
Soluble P	2.0	2.1	1.7	3.7	0.8	1.5	1.3
Denitrification Clarifier (mg/L)							
BOD	14.1	15.8	30.0	55	36.5	27	20
SS	25.8	15.5	26.7	36	15.6	19	20
TKN	3.1	2.9	6.9	23	9.7	4.7	2.2
NH_3-N	2.2	2.9	4.4	15	7.4	2.9	0.2
NO_2-N	1.4	4.6	2.3	0.2	0.7	0.8	0.3
NO_3-N	8.6	7.8	3.7	0.4	3.4	5.1	7.9
Total P	3.1	3.9	3.0	4.3	2.5	2.6	2.4
Soluble P	2.5	2.8	1.9	3.4	1.9	2.1	1.9

TABLE 3. NEWMARKET DENITRIFICATION RESULTS

(Mean Values)

Meth./NO_3-N Ratio	Average M.L. Temperature (°C)	Denit. M.L. (mg)O_2/L/hr	Denit. Applied (mg)	NO_3-N Reduced (mg)	Primary Effluent TKN	Primary Effluent NH_3-N	Secondary Effluent Tot-N	Secondary Effluent Sol-N
1:1	10.5	18	16	8.6	28	17	17	14
2:1	9.0	16	13	5.8	17	16	13	11
2:1	8.8	16	4.7	1.5	17	11	8.8	11
2:1	10.1	22	8.7	5.9	19	11	13	11
2:1	12.2	27	11	5.4	31	15	10	8.3
2:1	14.5	27	15	8.7	41	19	9	7.3
3:1	9.2	20	13	9.7	43	23	11	9.1
3:1*	13.0	23	14	9.8	26	17	7.3	4.5
Non-methanol								
	11.5	13	12	3.5	32	20	18	15
	7.5	9.8	11	1.2	22	14	12	12

*Ferrous sulphate addition to N-removal-aeration (5 mg/L as Fe).

TABLE 4. EFFECTS OF INFLUENT DO CONCENTRATION ON DENITRIFICATION

Range Aeration DO (mg/L)	Mean Denitrification Basin NO_3-N Reduced (mg)	Mean Denitrification Basin NO_3-N Reduced/g VSS (mg/g)
0-2	6.2	2.8
2-4	5.9	1.8
4	4.8	2.1

improvements were also reflected in ultimate effluent inorganic N values, which include ammonia, nitrite and nitrate portions. The non-methanol runs produced much less nitrate removal at similar temperatures.

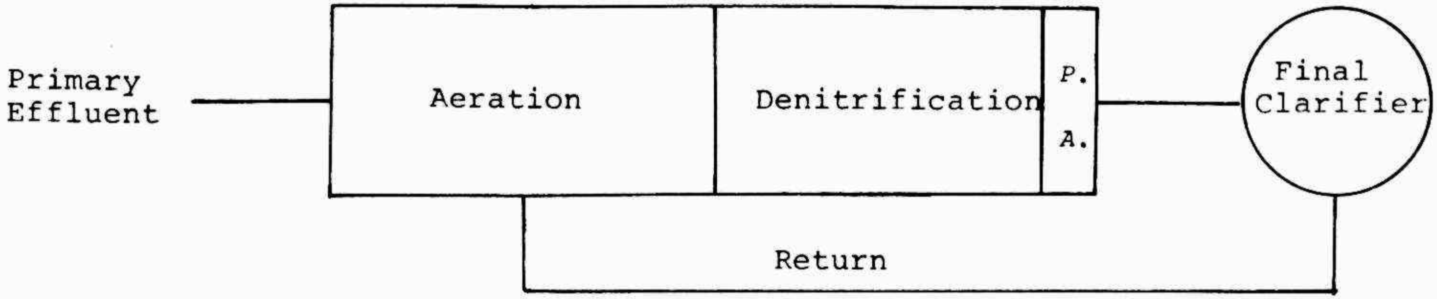
The influence of raised temperature on denitrification is also shown in Table 3, in some runs, as higher nitrate removals were produced at similar methanol addition ratios, (i.e., 2:1). Increase 0_2 uptake also, in most cases, coincided with increased nitrate and total inorganic -N removal. These patterns, along with the effects due to temperature, were similarly shown in non-methanol treated runs (Table 3).

(c) Effects of post-aeration. The post-aeration area did not entirely recondition the denitrification mixed liquor for final settling by effecting more complete settling but there were some noticeable changes in nitrogen forms through these sections. A survey of the data from March, April and May shows that when residual ammonia, unoxidized in the nitrification basin, was present further nitrification took place between the denitrification basin and the final clarifier (Figure 6).

(d) Effect of dissolved oxygen. On occasions when the dissolved oxygen level in the aeration mixed liquor (influent to denitrification basin) was maintained at 2 to 4 mg/L, denitrification reactions proceeded more efficiently than when higher M.L. DO was utilized. Evidence of this effect was seen in May when aeration DO was raised part of the month to accommodate the addition of ferrous sulphate for phosphorus removal. As shown in Table 4, the results during this period indicate a slight decrease in nitrate removal with an increase in aeration DO.

3.3.4 Difficulties caused by bulking sludge

Throughout the project high mixed liquor SVI (sludge volume index) was constantly experienced in both the control and N-removal units (Figure 7). Paralleled with high SVI were profuse growths of filamentous bacteria. Photomicrographs of these bacteria are presented in Photographs 3 and 4.



	NH_3	NH_3	NO_2	NO_3	NH_3	NO_2	NO_3	NH_3	NO_2	NO_3
March	12.9	10.3	0.5	4.5	9.4	0.5	1.8	7.4	0.7	3.4
April	13.6	3.3	0.4	11.0	2.9	0.8	5.9	2.9	0.8	5.1
May	17.8	0.1	0.2	15.0	0.5	0.4	8.8	0.4	0.3	7.9

FIGURE 6. N-REMOVAL UNIT SOLUBLE NITROGEN DISTRIBUTION

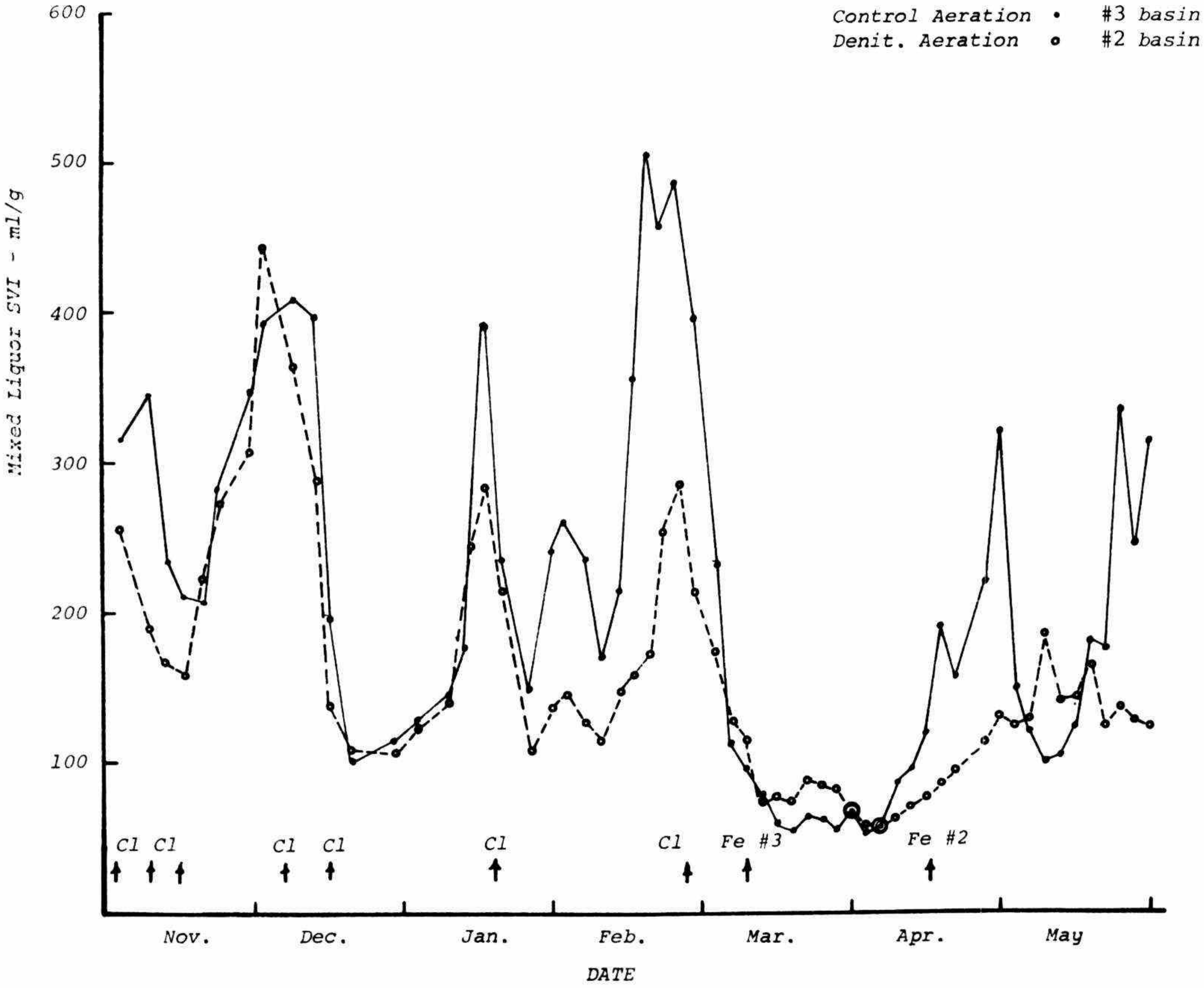
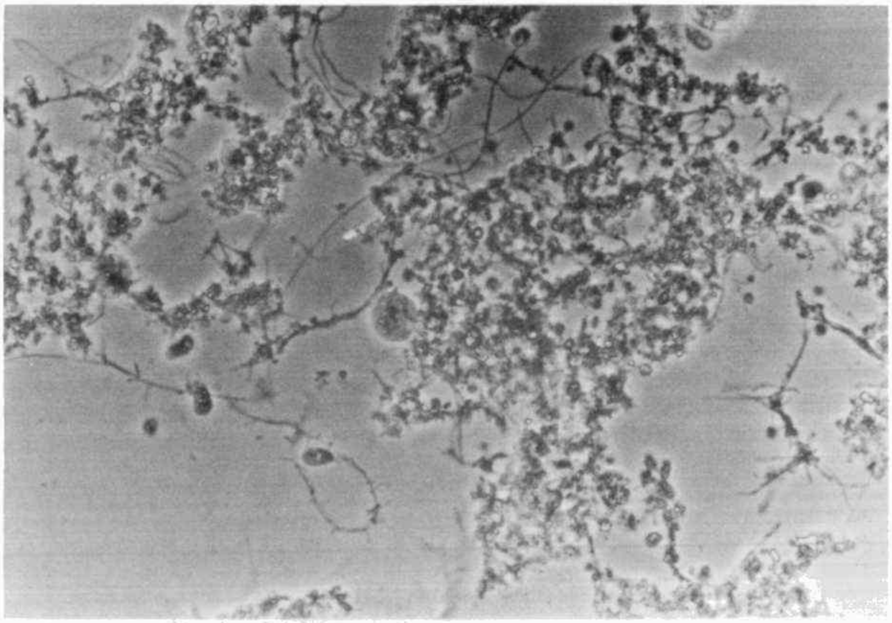
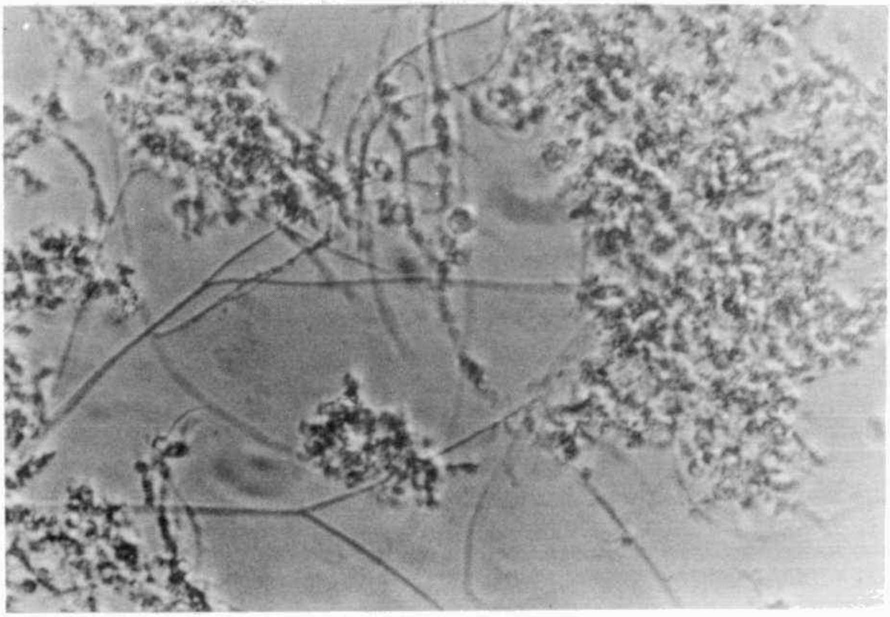


FIGURE 7. COMPARISON OF AERATION SVIs (NEWMARKET)



PHOTOGRAPH 3. NEWMARKET ACTIVATED SLUDGE FILAMENTOUS BACTERIA x 200 MAGNIFICATION



PHOTOGRAPH 4. NEWMARKET ACTIVATED SLUDGE FILAMENTOUS BACTERIA x 400 MAGNIFICATION

Final clarifier sludge bulking was experienced periodically when mixed liquor SVI rose above 250 ml/g, and resulted in a loss of process solids at peak diurnal flow periods. As seen in Figure 7, there were times when SVI were above 350 ml/g thus necessitating sludge treatment with chlorine for control of bulking.

Chlorination of the control unit return sludge flow was initiated at a dosage of 15 mg/L for periods of 24 to 48 hours during November. The return sludges from both the control and N-removal units were chlorinated periodically throughout the study when secondary clarifier bulking occurred. A drop in process M.L. SVI usually resulted, but a recovery of bulking conditions normally took place within 10 days of chlorine application.

Normally the aeration basin M.L. offered buffering to the influent primary effluent which varied from pH 8.5 to 10.5. Aeration effluent pHs averaged 7.5 to 7.8. During the aforementioned chlorination procedures, some of this buffering was lost as aeration pH's rose to 8.5.

In March, ferrous sulphate was added to the control aeration chamber at 5 mg/L as Fe^{+2} to enhance phosphorus removal. During this period, microscopic examinations of the activated sludge revealed a decrease in the number of large microorganisms including Vorticella and filamentous bacteria. Parallel with these findings were lowered SVI (190 to 70) and improved final effluent quality.

Ferrous salt addition to the denitrification aeration section was repeated in May and to the total plant during the summer following the termination of the nitrogen removal studies [15]. Similar improvements upon the aeration mixed liquor settling characteristics to those seen in March were observed, without any detriment to BOD removal or nitrification efficiency.

In Table 5 the mean monthly SVIs for the study are presented and a comparison between the denitrification basin and the control and N-removal units' aeration mixed liquor values are delineated. The denitrificaiton mixed liquor produced more than 30% higher SVI than did the preceding aeration #2 for the first half of the study. Comparatively, lower values were produced in the denitrification basin from

TABLE 5. SVI OF THE CONTROL AND N REMOVAL UNITS MIXED LIQUOR

	Mean Monthly SVI (ml/g)							
Basin/SVI (ml/g)	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	Average of Means
1) Control Aeration	269	270	185	353	87	146	187	214
2) N Removal Aeration	224	217	175	185	94	83	134	130
3) Denitrification	371	338	266	270	101	90	144	226
4) % Denit. of Control Aeration $\frac{3-1}{1} \times 100$	28	20	30	-31	14	-62	-30	-4
5) % Denit. to N Rem. Aeration $\frac{3-2}{2} \times 100$	39	36	34	31	7	8	7	23

March to May. A different pattern in SVI was seen on comparing the denitrification with the control aeration M.L. as either plus or negative results were attained.

3.3.5 Phosphorus removal and alkalinity

The results from the two units at Newmarket show that some soluble phosphorus was being regained via the denitrification mixed liquor reactions (Table 6). The control plant, without the anoxic section, more consistently retained the levels of soluble phosphorus of the primary effluent through to the final effluent, particularly during ferrous sulphate addition. As shown in Table 6, gains in soluble P produced in the sludges and final effluents of the denitrification section coincided with higher values of calcium alkalinity. Group averages derived from months February to May (Figure 8) indicate a definite relationship between the gain in alkalinity and the amount of phosphorus released under anoxic mixed liquor conditions of the denitrification chamber. The N-removal unit aeration basin showed similar alkalinity and phosphorus relationships but to a lesser extent. Comparison of the results of adding ferrous sulphate to the control and N-removal plant aeration chambers on separate occasions confirms the effects of denitrification on phosphorus release.

In March, with ferrous salt supplementation to the activated sludge at 5 mg/L as Fe^{+2}, the control plant exhibited a 15% rise in phosphorus removal giving final effluent levels of 1 mg/L or less of soluble P (Table 6). Conversely, the N-removal plant showed little change in phosphorus removal with similar additions to the aeration section in May.

3.3.6 Total nutrient removals

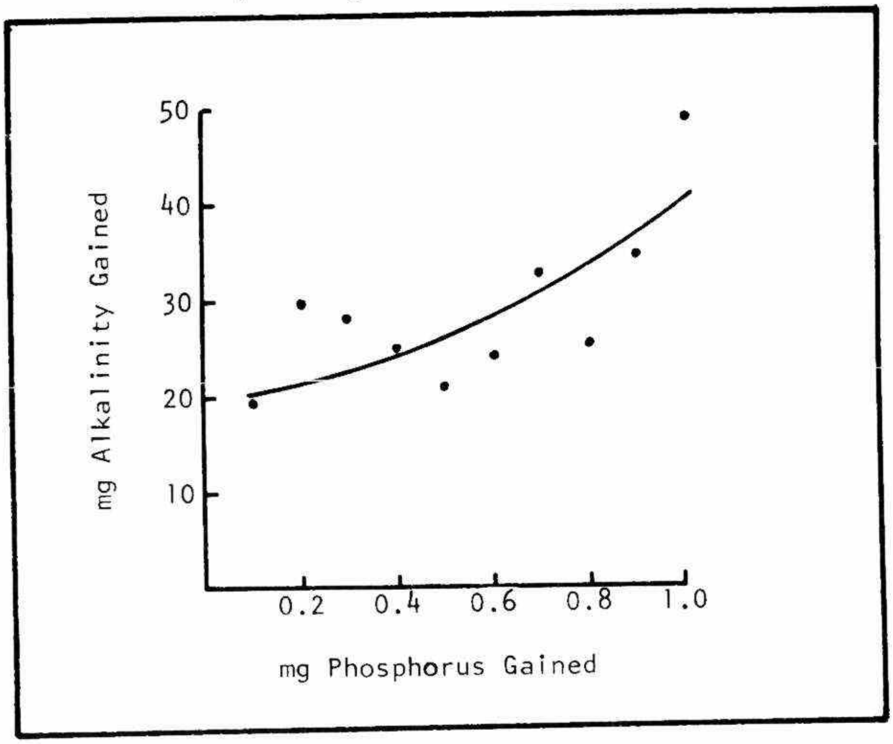
Table 7 shows the nutrient removal results from the complete Newmarket project. For the most part, suspended solids reduction in the control plant exceeded that in the denitrification unit, and this alone caused poorer BOD reductions in the denitrification units. Filtered carbon analyses revealed little or no carryover of methanol into the final clarifier effluent. Moreover, total organic carbon

TABLE 6. COMPARISON OF SOLUBLE PHOSPHORUS DISTRIBUTION IN CONTROL AND N REMOVAL UNITS

	FEBRUARY	MARCH	APRIL	MAY*
Primary Effluent				
Soluble P	1.9	1.6	1.6	1.2
pH	9.2	9.3	9.1	9.8
Alk ($CaCO_3$)	370	306	323	332
N Removal Aeration				
Soluble P	2.4	1.4	1.5	1.7
pH	8.0	8.2	7.8	7.8
Alk ($CaCO_3$)	330	282	240	184
Denitrification M.L.				
Soluble P	3.1	1.9	2.0	1.9
pH	7.8	8.0	7.7	7.8
Alk ($CaCO_3$)	351	301	270	228
Control Final				
Soluble P	3.0	0.8*	1.5	1.3
pH	7.8	8.0	7.7	7.8
Alk ($CaCO_3$)	275	258	217	178
N Removal Final				
Soluble P	3.4	1.8	2.1	1.9
pH	-	-	-	-
Alk ($CaCO_3$)	346	300	273	238

* Ferrous sulphate addition

Group Averages for February and May



Group Averages for March

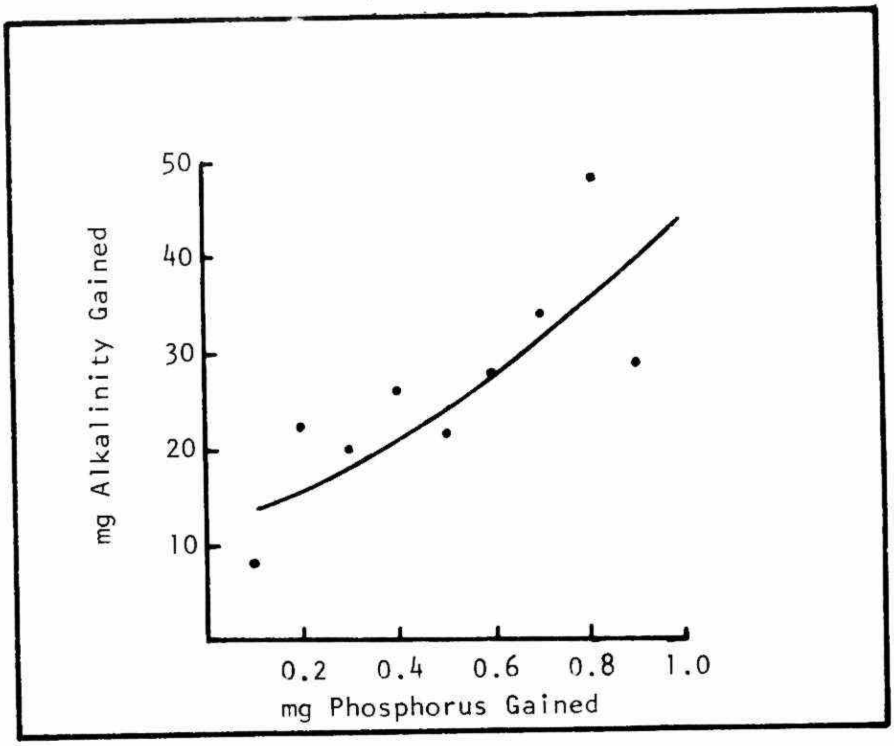


FIGURE 8. PHOSPHORUS GAINED BY CHANGES IN DENITRIFICATION ALKALINITY

(TOC) analysis indicated that most of the carbon form was utilized in the aeration chamber with no apparent differences being produced by denitrification reactions.

Chlorination of the return sludge during January and February for filamentous bacteria control reduced total nitrogen, phosphorus, and BOD removals in both control and denitrification units. Higher nitrogen removals, as a function of nitrate removal, were attained each month in the N-removal unit (Tables 2 and 7).

3.4 Discussion

Comparison of nitrification performances of the control and N-removal units suggests that the higher sludge return rate of the control unit led to a more rapid recovery following upset. This conclusion is somewhat substantiated by the batch tests which showed an improvement in nitrification rate in the N-removal aeration mixed liquor on increasing the return sludge quantity.

The adverse effects on nitrification seen by the addition of chlorine to the return sludge, particularly at lower wastewater temperature, show that this treatment may not be compatible with a nitrification process. Possibly, at higher temperatures, nitrification may not be inhibited as much by chlorination and higher bacterial growth rates will facilitate a rapid process recovery.

The conditions conducive to high nitrate removal in a denitrification basin, determined from previous reactor studies [1], are: i) suspended solids greater than 4000 mg/L, ii) raised endogenous respiration and/or iii) adequate organic carbon addition. These requirements were not maintained long enough during the study period to produce consistently high nitrogen removals. Sludge concentration was difficult to achieve. These conditions limited the attempts to thicken the denitrification mixed liquor while still maintaining aeration solids by either the split-return or alternate settling/mixing techniques.

These observations further emphasize the importance of solids control for the maintenance of nitrification and denitrification reactions. This would apply, particularly, when the maintenance of

TABLE 7. BIOLOGICAL PROCESS NUTRIENT REDUCTION
November - May, 1972 (Average Values in mg/L)

MONTH	Primary Effluent				N Removal NO_3-N		N Removal Final				Control Final			
	Total N	Total P	BOD	SS	Aer.	Denit.	Total N	Total P	BOD	SS	Total N	Total P	BOD	SS
NOV.														
AVG.	32	3.7	62	107	13	8.6	14	3.1	14	26	21	2.9	7.9	21
% Red.						28	53	18	77	76	33	22	87	81
DEC.														
AVG.	30	3.5	60.5	93.1	14	7.8	16	3.9	16	16	19	2.8	12	17
% Red.						46	48	0	74	83	37	3	86	82
JAN.														
AVG.	22	3.1	106	129	10	3.6	12	3.0	30	27	18.4	2.3	19	17
% Red.						64	45	0	72	79	18	26	81	87
FEB.														
AVG.	37	5.4	102	92	4.5	.4	23	4.3	55	36	23	4.8	65	52
% Red.						89	45	22	49	73	38	38	54	44
MAR.														
AVG.	22	4.2	77	104	4.8	3.4	14	2.5	37	16	17	1.3	28	13
% Red.						30	37	40	53	85	23	69	64	88
APR.														
AVG.	22	4.0	61	106	13	5.1	11	2.6	27	19	15	1.9	12	7
% Red.						61	52	35	52	82	30	52	80	94
MAY														
AVG.	27	3.7	80	98	15	7.9	10	2.4	20	20	18	1.6	18	9
% Red.						47	61	36	75	80	34	57	78	91

a high nitrogen removal at low temperatures was attempted.

Since the post-aeration section did not lower the denitrification mixed liquor SVI prior to secondary sedimentation, its role may be limited to stripping of residual methanol and/or as an oxygen supplement to the secondary effluent. Evidence shown as to the effects of aeration basin outlet dissolved oxygen on ultimate denitrification rate may mean that an automated aeration system set to maintain aeration D.O. between 2 and 4 mg/L would be desirable.

The actual cause of induced filamentous bulking sludge in both study units was not determined, although periods of low nutrient supply to the aeration section are suspected. Possibly, minute quantities of trace elements were continually precipitated out in the primary stages with the lime addition. Studies by Wood and Tchnobanoglous [16] have shown that small quantities of heavy metals are necessary in the activated sludge process to deter the growth of filamentous organisms. Low mixed liquor DO and excessive process loading have been ruled out as causes for induced high SVI as these conditions did not exist in the control plant.

The raised SVI seen in the N removal unit when nitrate reductions were enhanced suggest that denitrification reactions, as well, create a low density mixed liquor with possible deflocculation. With changes in mixed liquor characteristics, due to the aforementioned secondary clarifier detention, upflow rates etc. are critical parameters. If the clarifier had been larger at Newmarket, a better solids capture might have resulted, thereby cancelling the need for lowered SVI by chlorination.

The results at Newmarket show that presecondary lime addition for phosphorus removal was not capable of maintaining reductions above 80% total P in the N removal unit. Since this was a result of soluble phosphorus release in the denitrification basin, a supplementary dosing (probably with an iron salt) would be required downstream of this basin. Besides providing additional phosphorus removal, the addition of iron salt will improve sedmentation in the N-removal process, as occurred in the control unit at Newmarket.

4 PILOT PLANT STUDIES AT BRAMPTON AND KLEINBURG

4.1 Specific Objectives

The aims of this study were:

a) To evaluate the single-sludge, split-return arrangement for nitrification-denitrification under controlled conditions.

b) To determine if methanol addition was necessary for denitrification.

c) To monitor the effects of wastewater temperature on the single-sludge system.

d) To determine the value of a post-aeration basin following denitrification.

4.2 Description of Pilot Plant and Study

As full scale nitrification-denitrification studies approached termination at the Newmarket Nutrient Removal Facility, many limitations in the conventionally designed plant were realized. It was, therefore, decided that, for further in-depth study of the single-sludge process, a pilot plant should be fabricated incorporating the necessary flexibility in equipment required to operate and control factors such as: influent feed, aeration and sludge return rates.

An 830 gallon (3600 litre) pilot plant was designed, fabricated and mounted in an insulated house trailer. The plant was made portable so that, if required, it could be taken to various sewage treatment plants having different waste components. In this way, a comparison could be made between the operation of the pilot plant on domestic and domestic-industrial types of sewages.

The nitrification-denitrification pilot plant was of completely mixed, gravity flow, single-sludge design, as illustrated in Figure 9. Two tanks, each a four foot cube, served as nitrification and denitrification chambers. These two chambers were followed by a 6 foot high clarifier with a diameter of 2 feet. The lower third of the clarifier was occupied by a 60° conical settling zone. A 4 foot long centre well, 6 inches in diameter, was used surrounded by a launder tube 1 inch in diameter for effluent collection.

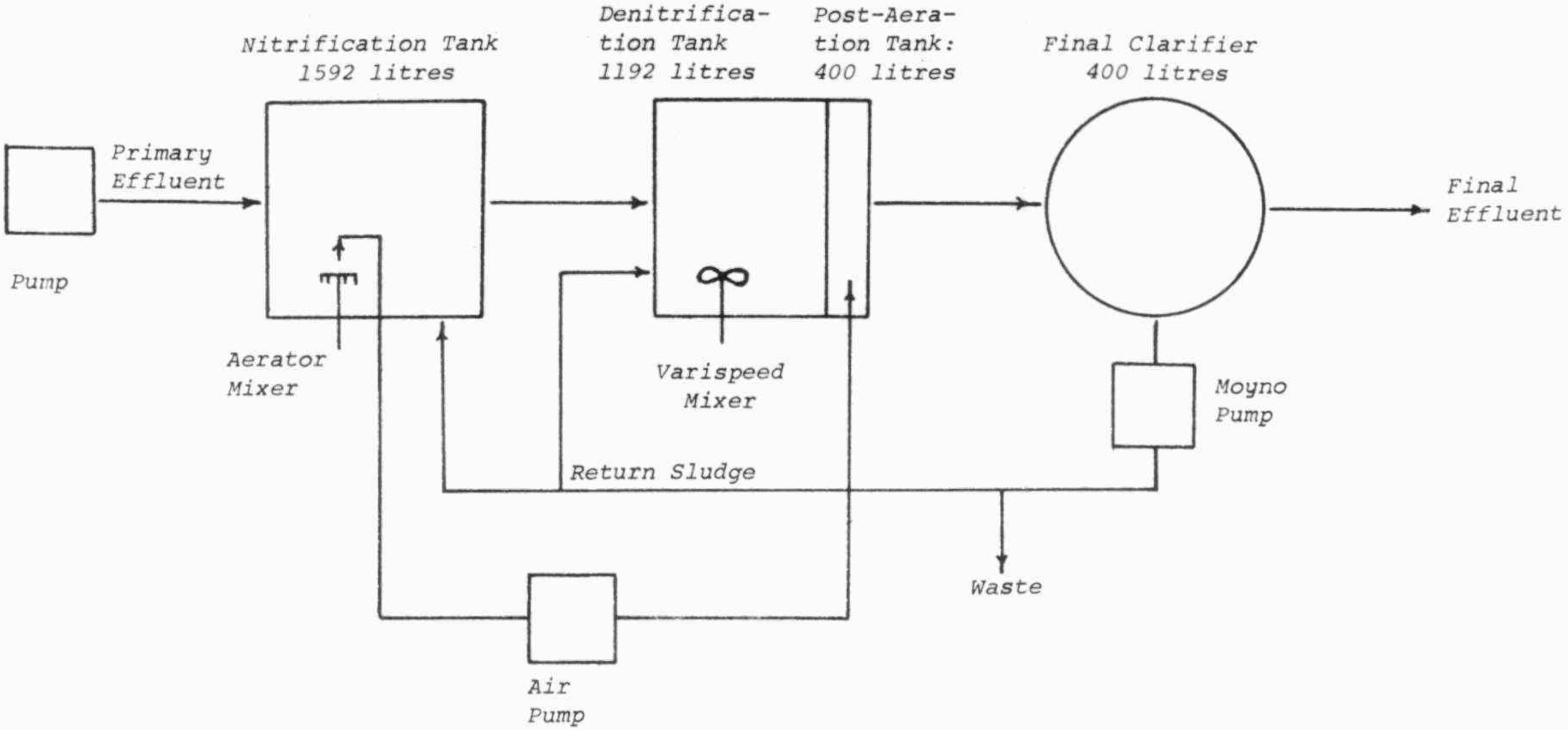


FIGURE 9. SCHEMATIC DIAGRAM OF THE NITRIFICATION-DENITRIFICATION PILOT PLANT

The plant was fed screened, raw sewage (simulated primary effluent) via a variable speed progressive cavity pump capable of giving a wide variety of feed rates. Air delivery to the aeration chamber was provided by a small air turbine system, and to the post-aeration chamber by a 10 cfm air pump and fine bubble diffuser.

The aeration mixed liquor then entered the denitrification tank by gravity where slow mixing was used to produce anoxic conditions. Post-aeration was provided in the clarifier centre well, or in the latter third of the denitrification chamber, by baffling a section with an adjustable plywood wall. This wall extended down to within 3 inches of the tank bottom. The mixed liquor in this post-aeration section was aerated with fine bubble diffusers.

The post-aerated mixed liquor entered the clarifier by gravity and the settled sludge was drawn off from the clarifer cone and returned to the nitrification and denitrification tanks by a variable speed progressive cavity pump.

4.2.1 Details of the pilot plant equipment

1) Primary effluent feed pump: Variable speed progressive cavity rated at 0.4 to 1.3 Igpm (1.8 to 5.8 L/min.).
2) Moyno return sludge pump: Variable speed progressive cavity rated at 0.1 to 1.5 Igpm (0.4 to 6.7 L/min.).
3) Air Pump: Oilless rotary air pump, carbon vane type, continuous 10 cfm (278 L/min.).
4) Mixer (nitrification) constant speed, 300 rpm, 3/4 hp.
5) Mixer (denitrification) variable speed 50-500 rpm, 1/3 hp.
6) Aeration chamber: Liquid volume of 358 Imp gal (1592 L).
7) Denitrification chamber: Total liquid volume of 268 Imp gal (1192 L).
8) Denitrification post-aeration section: Liquid volume of 96 Imp gal (427 L).
9) Clarifier: Total volume of 90 Imp gal (400 L) centre well volume of 28 Imp gal (125 L).

4.2.2 Sampling and analyses

1) Twenty-four hour composite samples of sewage influent and clarifier effluent were taken daily. Filtrates from each sample were refrigerated to ensure stability of soluble components. The following analyses were performed on these samples: biochemical oxygen demand (BOD), suspended solids (SS), ammonia, nitrite and nitrate, nitrogen, total and soluble phosphorus, total organic and inorganic carbon (TOC and TIC), chemical oxygen demand (COD) and alkalinity.

2) Composite grab samples of the nitrification and denitrification tanks mixed liquors were taken daily. Filtrates extracted from these samples were refrigerated. Suspended and volatile solids analyses were performed on the mixed liquors, and ammonia, nitrite and nitrate nitrogens, organic and inorganic carbon, COD and alkalinity analyses were done on the filtrates.

3) On-site tests consisted of half-hour sludge settling and oxygen uptake rates, pH, temperatures, suspended solids, ammonia and nitrate nitrogens. Nitrate analyses were performed with a specific ion electrode. This nitrate electrode was calibrated with a log function meter against a solution of sodium nitrate. The standard nitrate solution contained similar levels of chloride interference. The nitrate electrode measurements were used mainly to monitor the process and to regulate the methanol-to-nitrate ratios.

4) Samples were taken daily to the Ministry's Central Laboratory for complete chemical analyses.

4.2.3 Brampton pilot plant operations

As a preliminary test run, the pilot plant was located at the Brampton, Ontario Experimental Facility from June to October, 1973. A trailer laboratory accompanied the pilot plant for on-site routine testing of the plant's process (Photograph 5).

The Brampton-Chinguacousy Sewage Treatment Plant had been previously acquired from the South Peel Water Commission for wastewater treatment, research and training.

PHOTOGRAPH 5. BRAMPTON NITRIFICATION-DENITRIFICATION PILOT PLANT

In June, 1973, because facility was not in operation, a source of primary effluent was not available to feed the pilot plant. A raw sewage channel was, therefore, opened to low flow conditions and was used as a settling area from which sewage was drawn. Screening was installed at the pilot plant feed pump inlet to simulate primary effluent and prevent clogging of the plant's plumbing.

During the latter weeks of June, 1973, the pilot plant process was initiated by seeding the aeration chamber with the Malton WPCP return sludge. Within three days, good BOD removal was being achieved across the plant and the onset of ammonia oxidation occurred shortly thereafter (Figure 10).

In mid-July, mechanical difficulties were experienced with the plant aeration pump and mixer and, while changes were being made, the plant efficiency declined somewhat.

Simultaneously, raw sewage temperatures had risen to a high of 26°C due to the warm weather. This condition, combined with low weekend sewage flows though the settling channel, produced septic sewage. Often during weekend visits, a strong smell of hydrogen sulphide from the plant influent feed was noticed and the settling channel had to be flushed with fresh sewage. Filamentous bacteria over-population of both the aeration and denitrification sludges, along with a rise in the sludge volume index (SVI) was observed.

Chlorination at the pilot plant was instituted on July 24 in an attempt to deter the growth of filamentous organisms and reduce SVI. This procedure was continued well into August and various chlorine dosage points along the stages of the nitrification-denitrification plant were evaluated. After many trials, it was concluded that the most effective addition point was the clarifier-settled return sludge. Unfortunately, the extended chlorination experiments caused reduced nitrification and subsequently lowered dentrification efficiency. Furthermore, the filamentous bacteria quickly regained a foothold following each addition period. The sludge volume index dropped momentarily with chlorination but quickly rose with its cessation. Bulking in the clarifier was also experienced periodically.

On August 23, the plant chambers were flushed out and a fresh process was initiated without seeding. A post-aeration section was also installed at the end of the denitrification chamber to facilitate sludge conditioning before clarification. Further studies were conducted until early October, when the project was moved to Kleinburg.

The dissolved oxygen concentration in the aeration chamber was maintained between 2-4 mg/L for the duration of the study. The dissolved oxygen levels in the denitrification post-aeration section varied between 1-3 mg/L, later in the program.

The clarifier-settled sludge return rate was maintained at 100% of the influent flow. This return sludge was generally split in equal volumes to the aeration and denitrification chambers. When more solids were needed in the denitrification tank, more sludge return was diverted to that tank.

Methanol addition to the denitrification chamber, as a carbon supplement, was avoided because an evaluation of the process under summer temperatures, with solids thickening procedures only, was planned.

The data from the Brampton experiment were divided into three programs labelled B_1, B_2 and B_3. Each program encompassed results obtained from the effect of various imposed parameters such as sludge age, process loading, etc. (Table 8).

4.3 Brampton Results

4.3.1 Nitrification-denitrification and BOD removal

Virtually complete oxidation of ammonia to nitrate-nitrogen occurred in the pilot plant process during the first program (B_1), with a total sludge age of 30 days (Table 8). Mean values of effluent total nitrogen were approximately 8.0 mg/L and nitrate removals averaged 72%. Loss of nitrification occurred in the early part of program B_2 because of a solids loss due to clarifier bulking. As shown in Figure 10, nitrification was further impeded when chlorination of process sludge was carried out in an attempt to reduce bulking.

Recovery process nitrification (B_3) took approximately one month under slightly higher process loading conditions than in program B_2. Although program B_1 produced the lowest effluent nitrogen concentration (Table 8), the actual weight of nitrogen removed was highest in B_3 with increased process nitrogen loading and decreased sludge age (Table 9). Soluble oxidized-N removals (NO_2-N and NO_3-N) based on milligrams soluble nitrogen removed/milligrams denitrified VSS/day show values of 9.5, 0.4 and 15.6 for programs B_1, B_2 and B_3, respectively.

BOD removals as shown in Figure 10 were normally above 80% efficiency with the exception of the periods when chlorination was instituted. During this segment, even though a reduction to 50% efficiency occurred, this was much less drastic than the parallel losses in nitrification. Furthermore, a quicker recovery of BOD removal was observed following process re-establishment.

TABLE 8. BRAMPTON PILOT PLANT PROGRAM MEAN RESULTS

	Tank Liquid	Detention Time (hr)	
	Aeration	Denitrification	Clarifier
B_1 June, 1973	12.5	14.1	3.3
B_3 July, 1973	6.6	7.1	1.7
B_3 August to October, 1973	7.1	6.6	2.0

Primary Effluent	B_1	B_2	B_3
Sewage Temp. (°C)	21	23	25
BOD (mg/L)	167	145	143
SS (mg/L)	62	80	110
TKN (mg/L)	29	28	39
NH_3-N (mg/L)	17	16	19
Tot. P (mg/L)	8.1	7.9	10
Sol. P (mg/L)	5.1	5.7	6.3
TC (mg/L)	93	112	130
TIC (mg/L)	51	52	70
TOC (mg/L)	46	60	60
COD (mg/L)	156	180	173
Alk (mg/L)	235	231	239
Aeration M.L.			
SS (mg/L)	1592	1627	1248
VSS (mg/L)	1269	1334	966
F/M (lbs BOD_5/lb VSS)	0.18	0.38	0.63
SVI (ml/g)	307	641	371
O_2 Util. (mg O_2/L/hr)	20	37	27
SUR (mg O_2/hr/g VSS)	19	28	32
NH_3-N (mg/L)	0.8	8.0	11
NO_2-N (mg/L)	1.8	0.4	4.3
NO_3-N (mg/L)	9.3	1.8	5.3
TC (mg/L)	43	69	68
TIC (mg/L)	20	37	34
TOC (mg/L)	23	32	34
COD (Sol., mg/L)	32	52	64

TABLE 8 (cont'd)

Denitrification M.L.		B_1	B_2	B_3
SS		1528	1582	1634
VSS		1220	1278	1225
SVI	(ml/g	327	672	342
O_2 Util.	(mg O_2/L/hr)	22	44	26
SUR	(mg O_2/l/hr/g VSS)	19	40	21
NH_3-N	(mg/L)	1.9	8.7	11
NO_2-N	(mg/L)	1.3	0.2	2.9
NO_3-N	(mg/L)	3.4	0.6	2.7
TC	(mg/L)	49	69	65
TIC	(mg/L)	21	41	39
TOC	(mg/L)	28	30	26
COD	(mg/L)	38	55	54

Final Effluent

BOD	(mg/L)	22	45	28
SS	(mg/L)	26	53	24
TKN	(mg/L)	4.5	18	19
NH_3-N	(mg/L)	1.9	12	15
NO_2-N	(mg/L)	0.8	0.2	2.9
NO_3-N	(mg/L)	2.6	0.5	3.0
Tot. P	(mg/L)	6.0	7.7	8.1
Sol. P	(mg/L)	5.0	4.9	5.7
TC	(mg/L)	53	65	85
TIC	(mg/L)	28	37	53
TOC	(mg/L)	25	28	32
COD	(mg/L)	39	63	61
Alk	(mg/L)	162	192	240

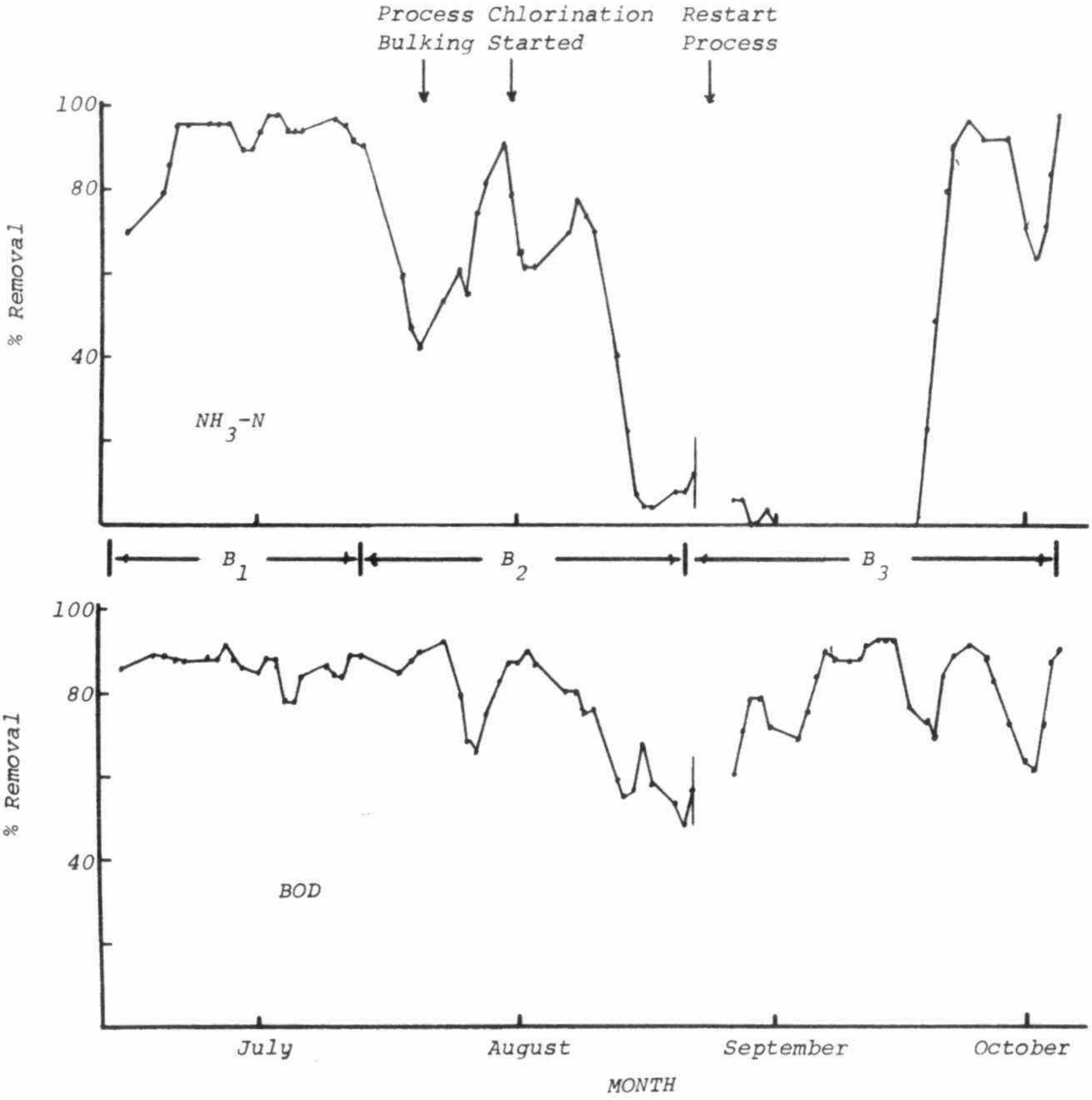


FIGURE 10. BRAMPTON PILOT PLANT BOD_5 AND AMMONIA REMOVAL

TABLE 9. BRAMPTON PILOT PLANT MEAN PROCESS REMOVAL RATES

Program	Sludge Age (days)		mg NH_3-N/g VSS/d		mg NO_3-N/g VSS/d		g Tot. N/d		% Tot. N Removal
	Total	Part. aer.	Applied	Removed	Applied	Removed	Applied	Removed	
B_1	30	15	24	23	13	9.6	84	61	73
B_2*	11	5.6	43	22	4.9	3.7	161	54	34
B_3	7.6	3.2	62	30	17	7.5	197	71	36

* Chlorination for filamentous infestation

4.3.2 Soluble carbon utilization

Figure 11, plotted from aeration mixed liquor filtrate results, shows an interrelationship of carbon and ammonia utilization, once the process is stabilized. The total carbon (TC) uptake rose and fell with the amount of nitrate produced by ammonia oxidation, and the chemical oxygen demand (COD) values paralleled these patterns.

Most of the carbon metabolism took place in the aeration chamber under aerobic conditions with seemingly very little change in TC levels through denitrification and clarification (Table 8).

Examination of the carbon data showed that although total organic carbon (TOC) was removed by the aeration process there was no clear relationship between this uptake and ammonia oxidation. Conversely, the total inorganic carbon (TIC) reduction correlated with nitrification reactions (Figure 12), so that TIC uptake increased with improved nitrification.

4.4 Kleinburg Pilot Plant Operations

In early October the nitrification-denitrification pilot plant was moved to the Kleinburg WPCP which is an extended aeration plant treating domestic waste from the Town of Kleinburg. Alterations were made to the pilot plant denitrification chamber and post-aeration section to prevent air entrance to the dentrification area. As the value of the post-aeration section had not been fully tested at Brampton, this evalution was made at Kleinburg.

In mid-October, the pilot plant's processes were initiated with aeration mixed liquor from the Kleinburg WPCP. The pilot plant feed was drawn from the Kleinburg plant's raw sewage channel and was screened through several layers of wire mesh to produce a simulated primary effluent.

The nitrification tank dissolved oxygen level and the sludge return rates were maintained the same as those of the Brampton study. Attempts were made to keep the food-to-microorganism ratio (F/M) between 0.1 to 0.3 gm BOD/day/gm aeration chamber suspended solids during startup and regular runs. Feed rates and detention times were similar to those in program B_3 of the Brampton study.

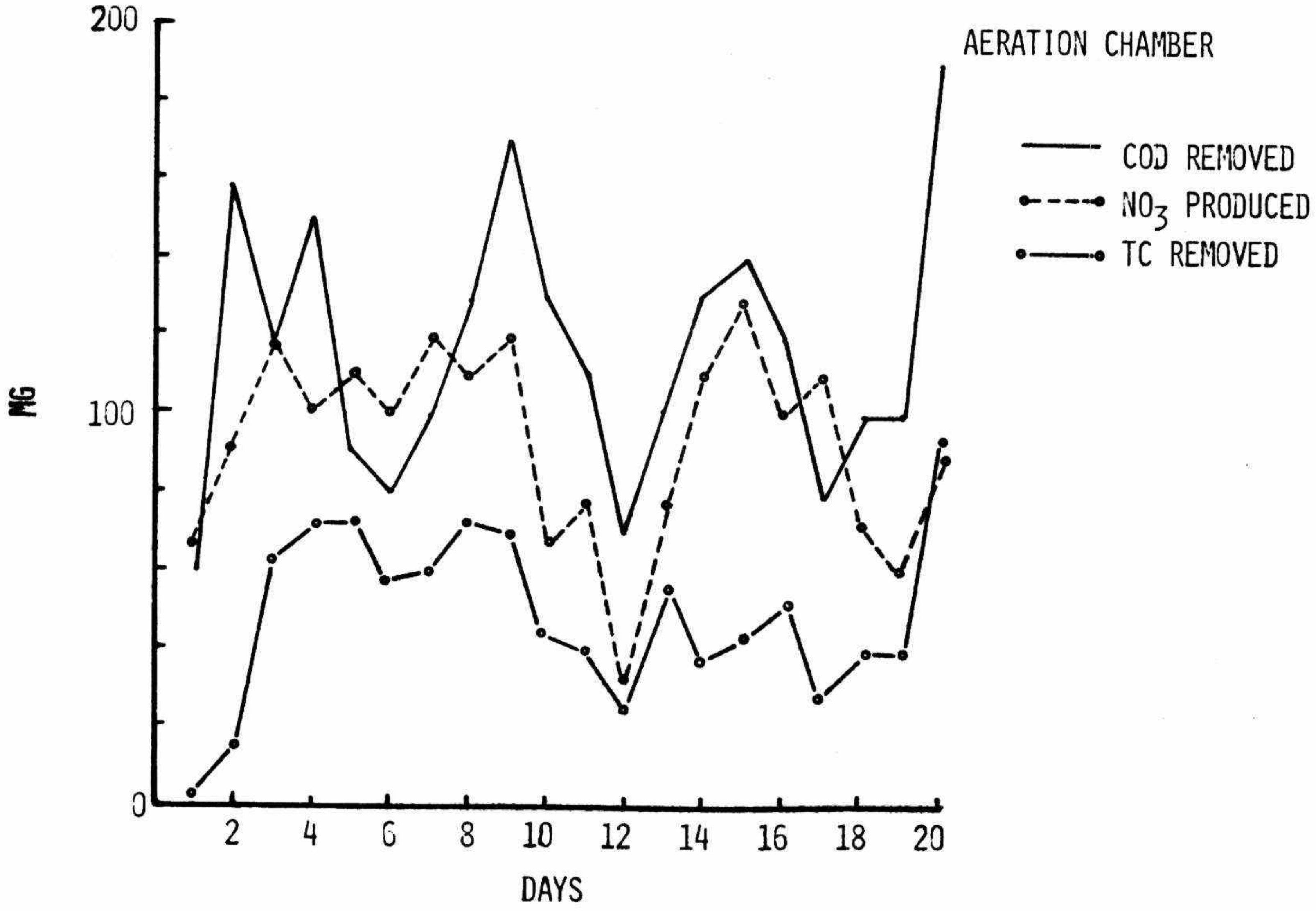


FIGURE 11. NITRATE PRODUCTION AS RELATED TO TC AND COD REDUCTION (BRAMPTON) (PROGRAMS B_2 AND B_3)

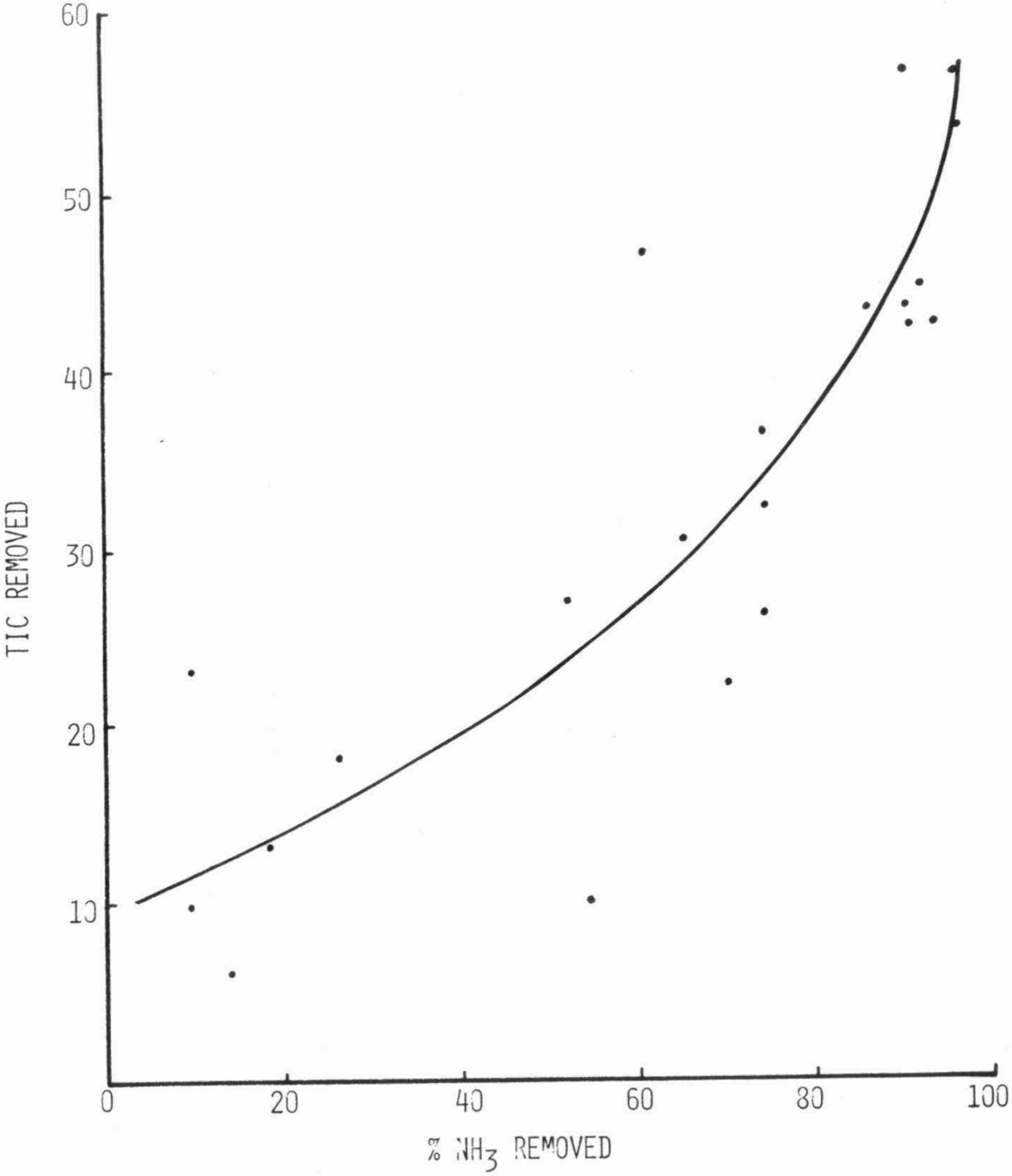


FIGURE 12. TOTAL INORGANIC CARBON REMOVAL VS NITRIFICATION (BRAMPTON)

A series of 10 programs, labelled K_1 to K_{10}, was conducted at Kleinburg with durations of two to six weeks (Figure 13). Evaluation of the system with various dosages of methanol, with and without post-aeration, and with ferric chloride addition for phosphorus removal was attempted.

4.4.1 Kleinburg results

4.4.1.1 Nitrification-denitrification. During most of November (program K_1), at mean sewage temperatures of 16°C, little or no ammonia oxidation (nitrification) occurred in the pilot plant (Table 10). BOD_5 removal was established during this period and by the end of November and during the first week of December (K_2) nitrification was being achieved in the aeration chamber (Figure 13). Nitrification efficiency then remained above 95% except for a segment of program K_9 when chlorination of the process was attempted for control of sludge bulking.

As shown in Table 11, mean ammonia removal rate of 23 mg NH_3-N/g VSS/day resulted once nitrification was established. A total sludge age of 12 days and a partial sludge age (aeration chamber only) of five days resulted, with no correlation with ammonia removal rate being indicated above these values.

As reflected in the total nitrogen removals plotted in Figure 13, denitrification (nitrate and nitrite removal) was observed through K_3 and K_4, as consistent levels of oxidized nitrogen were maintained in the aeration chamber. Methanol addition to the denitrification chamber was initiated early in program K_3 and was gradually raised to an addition ratio of 4 g of methanol per g of NO_3-N. The process maintained good nitrogen removals at these methanol dosages until mid-January (K_4) when a reduction in nitrogen removal occurred as a result of lowered nitrate reductions. This was thought to be due to a drop in sewage concentration caused by stormwater infiltration to the Kleinburg WPCP. A loss of solids occurred in both the aeration and denitrification chambers (Table 10) as the influent BOD_5 fell below 70 mg/L. During this period,

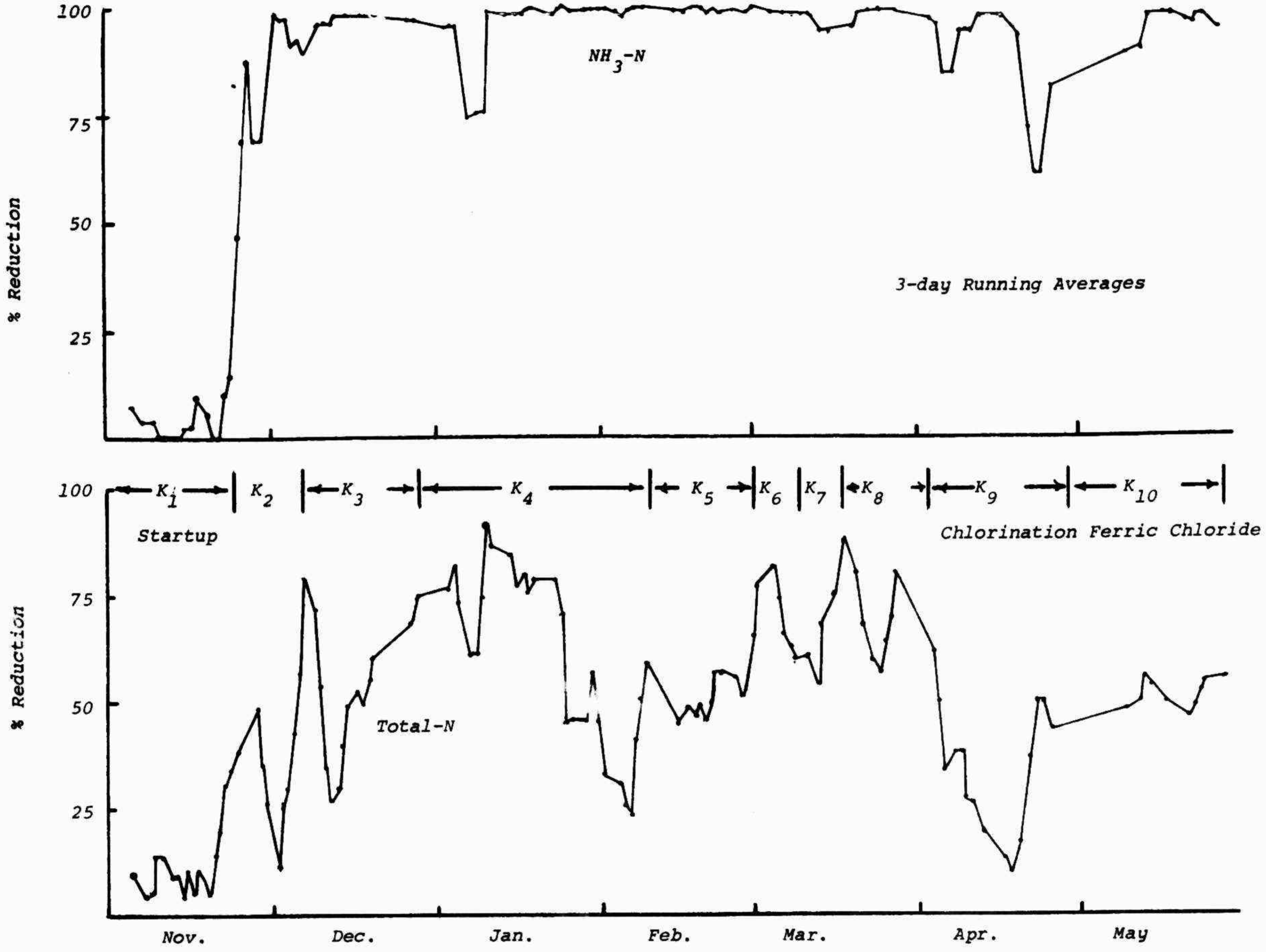


FIGURE 13. PILOT PLANT AMMONIA AND TOTAL N REDUCTIONS (KLEINBURG)

TABLE 10. KLEINBURG PILOT PLANT ANALYTICAL RESULTS (Mean Values)

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}
Primary Effluent										
Temp. (°C)	16	17	15	13	13	13	10	11	12	14
BOD	102	50	70	68	125	85	71	90	81	77
BOD (Soluble)	28	18	21	26	24	12	14	19	18	16
SS	104	56	70	70	118	121	100	85	82	138
NH_3-N	2	2	21	22	19	17	22	22	19	17
TKN	35	30	30	33	39	24	31	41	30	28
Total P	7.7	6.5	7.0	6.7	8.2	5.3	6.7	8.0	6.3	6.5
Soluble P	5.7	4.5	5.1	4.4	4.7	2.9	4.7	4.9	3.8	3.3
TC	125	108	103							
TIC	87	84	70							
TOC	38	25	33							
COD (Soluble)	86	58	62	68	81	35	80	87	62	48
Alkalinity	386	377	373	381	379	326	386	386	361	388
Aer. Mixed Liquor										
SS	2171	2180	1750	1956	1978	2530	2011	2715	1734	3631
VSS	1786	1756	1382	1672	1696	1984	1617	2283	1449	2914
F/M BOD/VSS	0.16	0.10	0.13	0.14	0.41	0.17	0.20	0.13	0.21	0.09
SETG	20	23	20	29	48	58	40	76	46	79
SVI (ml/g)	94	107	117	150	238	210	241	269	260	228
O_2 used (mg/L/hr)	26	29	24	25	29	24	24	22	19	26
NH_3-N	23	6.8	1.9	3.5	3.0	3.5	2.8	0.51	5.3	2.5
NO_2-N	0.5	5.7	1.3	1.1	1.9	1.1	0.64	2.7	2.0	1.6
NO_3-N	0.56	5.9	17.5	13	16	14	11	17	13	12
TC	111	76	68							
TIC	86	61	48							
TOC	26	15	20							
COD (Soluble)	58	27	31	32	38	28	37	37	20	27

TABLE 10. (cont'd)

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}
Denitrification Mixed Liquor										
Methanol	none	none	3:1	3:1	4:1	5:1	5:1	3:1	none	(variable)
SS	3044	3930	3586	2758	3998	5017	4319	5390	2735	3864
VSS	2496	3173	2900	2301	3473	4022	3583	4367	2297	3102
SETG	49	49	43	72	93	96	97	97	92	80
SVI (ml/g)	158	131	133	264	237	196	225	188	342	214
O_2 used (mg/L/hr)	30	40	25	32	31	32	33	16	26	23
NH_3-N	22	3.7	0.27	0.6	0.4	1.2	1.0	0.15	1.6	1.7
NO_2-N	0.37	3.6	0.3	0.6	1.7	0.66	0.21	1.2	1.2	1.0
NO_3-N	0.52	4.3	11	7.4	11.2	3.3	0.3	11.3	13	8.1
TC	110	77	69							
TIC	85	61	53							
TOC	28	15	21							
COD (Soluble)	60	25	35	30	36	22	29	37	29	27
Final Effluent										
NH_3-N	23	2.3	0.4	4.1	0.15	0.1	0.8	0.2	2.3	0.9
NO_2-N	0.97	4.5	0.19	0.16	0.16	0.06	0.33	0.07	0.71	0.26
NO_3-N	0.54	7.3	12	7.5	13.5	4.4	1.0	12	17	10
TKN	28	4.3	2.4	4.5	3.6	2.4	7.7	3.0	3.5	1.9
SS	44	22	16	17	19	11	54	19	10	15
Total P	5.5	5.2	5.7	5.1	5.9	4.2	6.3	5.8	4.7	3.1
Soluble P	4.3	3.9	5.3	4.6	4.6	3.1	4.6	4.7	3.4	2.8
BOD	37	15	9.4	15	19	6.8	32	12	22	15
BOD (Soluble)	11	3	6	5	4	5	8	4	5	4
TC	111	78	72							
TIC	87	60	50							
TOC	23	16	20							
COD (Soluble)	53	25	33	27	35	23	27	41	33	26
Alkalinity	375	253	266	265	239	246	302	241	239	252

TABLE 10. (cont'd)

	K_1	K_2	K_3	K_4	K_5	K_6	K_7*	K_8	K_9	K_{10}
Program Avg. % Reductions										
NH_3-N	5.4	88	97	96	97	99	96	99	87	94
BOD	49	66	87	77	84	92	55	84	70	68
SS	49	57	74	72	81	91	46	83	88	78
Total P	29	18	21	24	26	42	6	27	25	52
Soluble P	25	14	0	0	0	0	0	5	11	15
NO_3-N	8.8	21	30	49	22	70	91	31	8	12
Total N	14	32	54	60	52	60	59	68	31	53
TC	11	26	27							
TIC	0.4	31	27							
TOC	30	27	27							
COD (Soluble)	36	46	44	58	56	59	66	50	43	47
Alkalinity	4.5	31	28	38	35	24	22	37	33	33

* Post aeration removed

Note: All results are reported as mg/L unless otherwise stated

BOD:TKN ratio (not including the periods of constant methanol application) changed from a (dry flow) mean of 2.4:1 to a ratio of less than 1.5:1 under wet weather flow conditions. The mean total sludge age was 23 days for program K_4 (Table 10), but during the seven days of runoff the total sludge age rose to 32 days.

Total nitrogen removal rate recovered to 50% in program K_4 (Table 10 and Figure 13) and rose to 60% in K_6 when the methanol to nitrate dosage ratio was increased to 5:1 and denitrification solids rose above 3000 mg/L. Normally the total nitrogen removal was a function of nitrate reductions within the denitrification chamber. The exception to this was in program K_7 when, after temporarily removing the post-aeration section, nitrate reductions of 91% with effluent levels of 1 gm/L NO_3-N were produced but total nitrogen removals were only 50% (Tables 10 and 11). The cause of this was an increase in effluent organic nitrogen due to higher suspended solids concentration. Furthermore, residual concentrations of DO of 0.2-0.5 mg/L previously measured in the denitrification chamber mixed liquor dropped to zero.

A sharp drop in nitrate removal occurred in program K_8 when the post-aeration was reinstituted with a methanol-to-nitrate ratio of 3:1. The nitrogen removal increased to 68% (Table 10) with improved suspended solids removal and a reappearance of denitrification chamber DO.

A decrease in nitrogen removal in program K_9 resulted from chlorination of the sludge and a reduction of the denitrification solids concentration. Only a slight recovery in nitrate reduction was observed in May (K_{10}) during ferric chloride addition for phosphorus removal.

Oxygen utilization rates (mg 0_2/L/hr) were measured daily throughout the study in both the aeration and denitrification chambers (Table 10). With the exception of programs K_8 and K_{10}, the 0_2 utilization levels in the denitrification chamber were 4-40% above the level obtained in the aeration chamber. No correlation was indicated between 0_2 uptake rate or specific uptake rate (mg 0_2/hr/g VSS) and the ultimate nitrate removal efficiency.

TABLE 11. KLEINBURG PILOT PLANT MEAN PROCESS NITROGEN REMOVAL RATES

Program		Mean Sludge Age (days)		Ammonia-N (mg/g VSS/day)		Nitrate-N (mg/g VSS/day)		Total N (g/day)	
	Methanol	Total	(Part. aer.)	Applied	Removed	Applied	Removed	Applied	Removed
K_1*	none	15	6	23	0	1	0	181	25
K_2	none	34	12	33	23	7.6	2.9	156	73
K_3	3:1	23	7	40	37	19	6.8	160	85
K_4	3:1	21	9	36	30	31	11	166	91
K_5	4:1	14	5	36	30	22	6.6	230	106
K_6	5:1	18	6	30	21	17	13	180	112
K_7**	5:1	16	5	37	31	10	10	163	129
K_8	3:1	28	9	28	27	18	5.5	224	164
K_9***	none	16	6	38	27	24	0	164	53
K_{10}	variable	13	6	19	16	20	6.3	181	123

* Process startup

** Post-aeration removed temporarily

*** Chlorination of process sludge

As shown in Table 11, mean ammonia removal rates were consistently maintained in the pilot plant once nitrification was established. No relationship was indicated between the total or partial sludge age (within the ranges studied) and ammonia oxidation. Some relationship was indicated beween nitrate removal rate in the denitrification chamber and sludge age regardless of methanol addition when the process was stable (between K_2 and K_8).

4.4.1.2 Alkalinity changes. With the onset of nitrification during November and early December (K_1 and K_2) an increase in total alkalinity removal was noted from a mean of 4.5% in K_1 to 31% in K_2 (Table 10). The influent and effluent alkalinities during this period are plotted in Figure 14 along with values of oxidized ammonia-N. Total process alkalinity removal rose with parallel rises of oxidized ammonia-N. Total process alkalinity removal rose with parallel increases in ammonia oxidation.

A slight reversal in this pattern was seen when denitrification reactions were established within the process in the latter part of K_2 and into program K_3 as the percent alkalinity removal decreased with increased nitrate reduction (Table 10). Mean values in milligrams of alkalinity reduced per milligrams ammonia-N oxidized were 6.7 with less than 35% nitrate removal and 4.9 with more than 35% nitrate removal.

4.4.1.3 Sludge volume index (SVI). A significant rise in SVI occurred in the pilot plant with the onset of nitrification and denitrification reactions. As illustrated in Figure 15, a gradual upward trend in aeration SVI resulted during and after the onset of nitrification. Post-aeration SVIs normally followed those of the denitrification chamber, consequently, when post-aeration SVIs rose above 330 ml/g in program K_9, clarifier performance deteriorated due to an increased sludge blanket.

Chlorination of the return sludge at 30 mg/L during three days of application in program K_9 did not significantly change process SVI values. A change did take place, however, with the

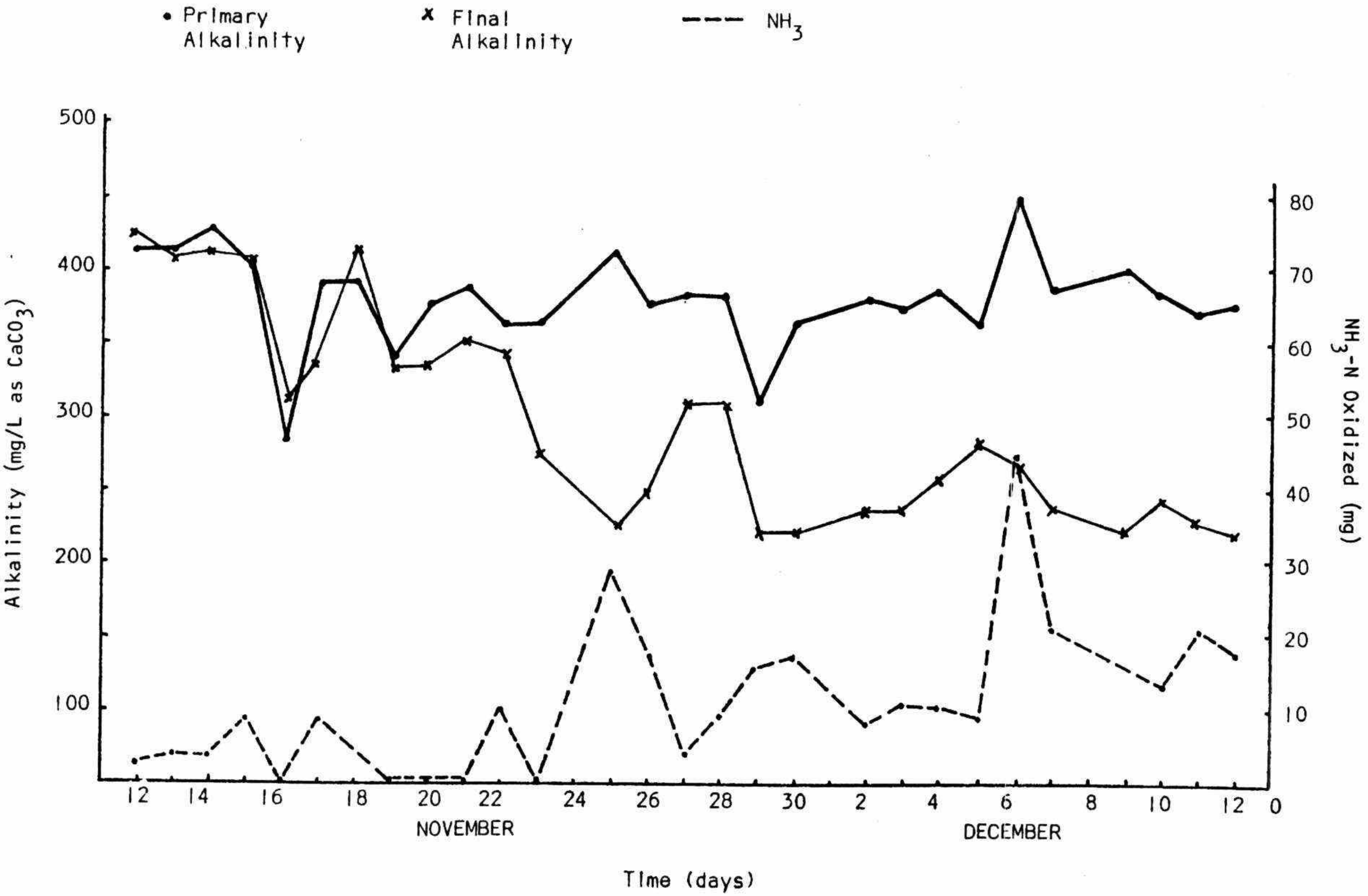


FIGURE 14. ALKALINITY LOSS VS AERATION NH$_3$ OXIDIZED

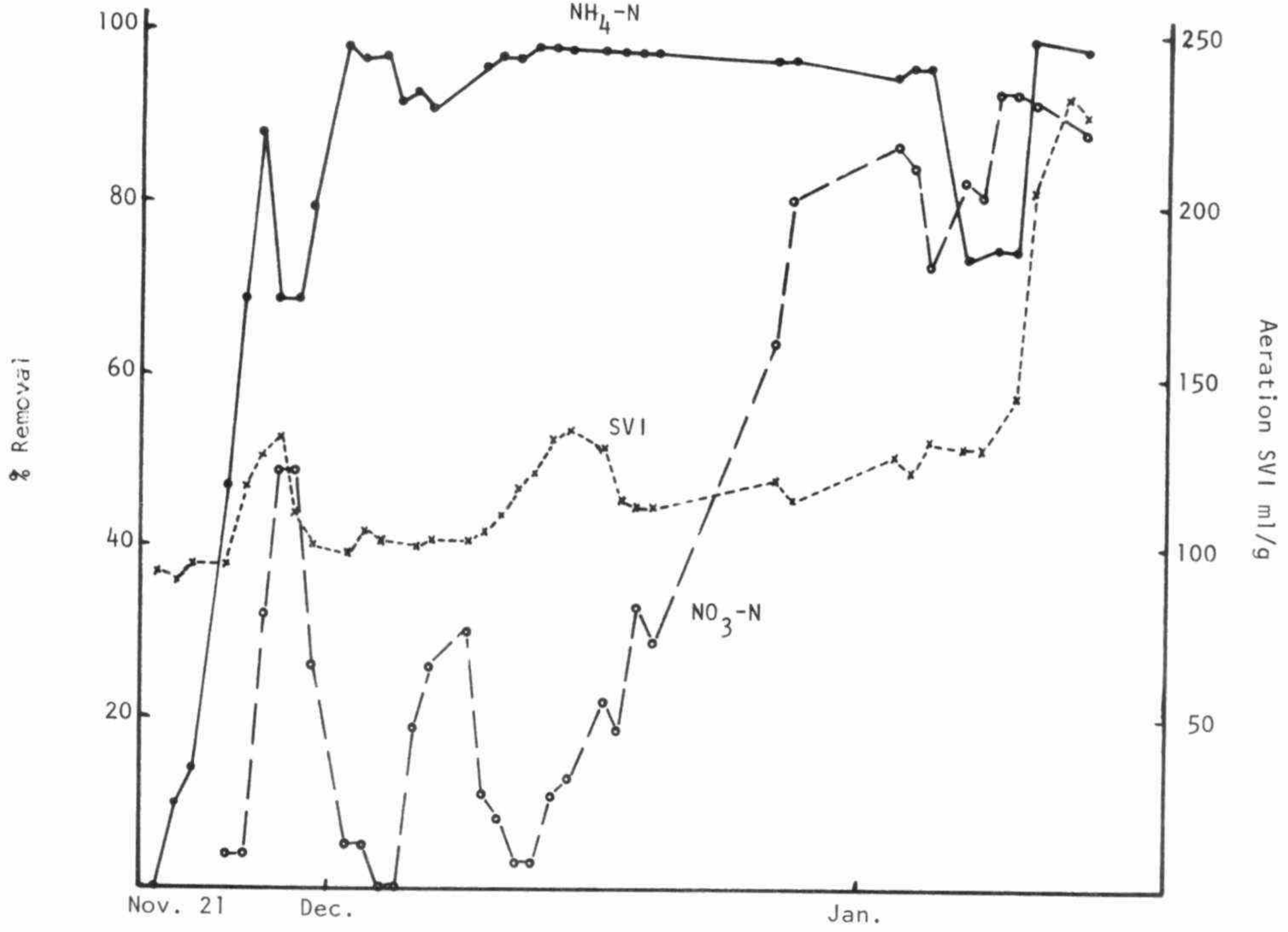


FIGURE 15. EFFECT OF TOTAL PROCESS NITROGEN UTILIZATION ON SVI (KLEINBURG PILOT PLANT)

addition of ferric chloride in program K_{10} (Table 10) as denitrification SVIs gradually receded to values of about 200 ml/g over a 20-day addition period.

4.4.1.4 Phosphorus removal. The program mean % reductions in phosphorus as presented in Table 10 show that removals approaching 50% were attainable only with a high suspended solids removal (K_6) and/or precipitation of soluble P with ferric chloride (K_{10}).

Once nitrification-denitrification was established in the pilot plant, soluble phosphorus uptake dropped to zero (K_3 to K_7). A recovery of soluble P uptake occurred with lower nitrate removals in programs K_8 and K_9.

4.4.1.5 Biochemical and chemical oxygen demand (BOD and COD) removals. A marked improvement in the clarified effluent was observed with the onset of nitrification in the aeration chamber (K_2). This visual observation is supported by the data in Table 10 in which a drop in both soluble in insoluble BOD is shown through programs K_1 and K_3. Clarifier effluent BOD values remained consistently below 20 mg/L following process stabilization until program K_7. The removal of the post-aeration chamber (thereby enlarging the denitrification chamber) produced a sharp increase in effluent total BOD with raised soluble BOD and suspended solids. Improved BOD and suspended solids removal resulted after reinstation of the post-aeration chamber in program K_8.

The onset of nitrification effected a 50% reduction in effluent COD levels from program K_1 and K_2. Mean program effluent values varied between 25-41 mg/L after program K_1.

4.5 Discussion of Brampton and Kleinburg Results

Differences between process maturation times at Brampton and Kleinburg are shown in relation to the onset of nitrification. The sludge age and wastewater temperature were higher during initial startup at Brampton than at Kleinburg but it would seem that temperature was more of a controlling factor. This conclusion is supported by results in program B_3 when, at a lower sludge age and higher wastewater temperature, a relatively rapid recovery of nitrification efficiency was obtained.

Partial loss of ammonia oxidation efficiency occurred during one period (B_2) with an abrupt change in sludge age but, generally, the range of sludge age attained at both pilot plant sites was adequate to maintain full nitrification under variations of wastewater temperature. Major deterioration in nitrification was seen when chlorine was added to the return sludge. This is felt to be a result of toxic effects upon nitrification bacteria.

No loss in nitrification efficiency was noted when a high denitrification was taking place in the process. Consequently, the return of the denitrified sludge to the aeration basin was not seen as a deterrent to ammonia oxidation reactions.

Since TIC uptake correlated with aeration ammonia oxidation, autotrophic bacteria were probably responsible for nitrification. These bacteria require an inorganic carbon source for oxidation reactions.

Concentrating solids in the denitrification basin above 200 mg/L was difficult because of a low growth rate and losses due to clarifier bulking midway through the Brampton study. The better nitrate removals obtained in program B_1 were probably due to lower process loadings and longer denitrification chamber detention times.

More consistent nitrate reduction in the pilot plant at Kleinburg is felt to be a result of maintaining higher denitrification mixed liquor solids and methanol addition. Adequate solids concentration in the dentrification chamber was attained by increasing the portion of the return above 50% of flow to that chamber.

By comparison, non-methanol addition segments produced lower nitrate removals than did the similar segments at Brampton which had the warmer influent wastewater temperatures. Nitrate removal rates obtained at Brampton (B_1) without methanol addition suggest that, depending on effluent requirements, methanol may not be required during the summer.

Evidence from the Kleinburg study that the BOD/TKN ratio of the influent wastewater affects ultimate denitrification may mean that supplemental organic carbon addition may be required. This would be required more during the period of dilution by storm water, particularly if bypassing of primary effluent is practiced to reduce hydraulic loading to the secondary stage. This finding relates somewhat to results reported by Bishop et al [12] and noted earlier in this report, on the effects of lowered COD/TKN ratio on denitrification.

When the post-aeration was removed in program K_7, a marked increase in nitrate reduction occurred in the denitrification chamber. This could have been, in part, a result of the extra hour in the dentrification chamber. Denitrification chamber DO concentration may also have been a factor, as these levels dropped to zero without the post-aeration in service. A separate or more efficiently sealed post-aeration area would prevent transfer of oxygen to the denitrification mixed liquor, and improve nitrate removal.

Higher than expected methanol quantities (5:1 ratio) were required to produce adequate nitrate removal while a 3:1 ratio was sufficient in the previous reactor studies [1]. The extra requirement could possibly be due to dissolved oxygen transfer from the post-aeration to the dentrification chamber. This would probably occur more during the evening when process loading and oxygen utilization rates would likely be lower.

The resultant rise in clarifier effluent suspended solids, upon removing the post-aeration, illustrates the need for such a facility to produce adequate effluent quality from this type of process arrangment. Otherwise, a tertiary filter may be required to produce a BOD or suspended solids concentration of less than 15 mg/L.

The reduction of alkalinity (as $CaCO_3$) that occurred in the Kleinburg pilot plant, when only nitrifying, compares well with the range of 6 to 7.5 mg alkalinity per mg ammonia oxidized found by other investigators [17]. The gain in alkalinity in the denitrification chamber could be viewed as a plus factor, particularly if this process were to be implemented on a low alkalinity wastewater.

The release of soluble phosphorus, once denitrification was established, was evident in the pilot plant studies as it was in previous experiments at Newmarket discussed earlier in this report. Moreover, the dosage of 5 mg/L ferric chloride (as Fe) did not produce sufficient phosphorus reduction to attain Ontario Ministry of the Environment effluent guidelines of 1 mg/L P. Because of the positive effect of the ferric chloride addition in the lowering of process SVI, this or other chemicals may be needed for this purpose. The process seems to produce a sludge of higher than normal SVI which could not be adequately reduced by conventional sludge chlorination techniques, without disrupting nitrification reactions.

In summary, the single-sludge process, using the split-return configuration, appears capable of providing nitrate removal. The advantage of this arrangement is that interstage clarification and sludge recycle is not required as with a two or three-sludge system.

The main disadvantage of the system studied here is the inherent high SVI. This probably is a result of deflocculation and filamentous organism growth due to great process sludge age. Greater than normal requirements for secondary clarification may thus be needed for this system, unless SVI can be lowered by iron salt or other chemical addition.

APPENDIX B

METEOROLOGICAL DATA

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APPENDIX A

NEWMARKET PROJECT OPERATION SUMMARY

APPENDIX A

NEWMARKET PROJECT OPERATION SUMMARY

DATE:	OPERATION AND OBSERVATIONS
Sept. 6-28, 1972	- Start full scale plant operations using combined sludge return system. - Both aeration SVI rising slightly.
Sept. 28-Oct. 31, 1972	- Return system divided to give two completely separate plants on October 13, 1972. - Signs of bulking in control aeration on October 15. - SVI at 170 - Sludge bulking in control Final clarifier on October 19 - SVI at 370 - Severe bulking in control Final clarifier on October 30 - SVI at 420
Nov. 1-27, 1972	- Chlorination of control unit's return sludge for filamentous bacteria - November 1-14. - Return of N-removal plant split between aeration and denitrification chambers. - Denitrification clarifier bulking on November 20, 1972.
Nov. 28-Dec.12, 1972	- Methanol added to denitrification chamber, ratio of 1:1 to nitrate concentration. - Control and clarifiers bulking on 8th. - Total plant chlorination started on 6th.

DATE:	OPERATION AND OBSERVATIONS
Dec. 13-28, 1972	- Filamentous bacteria growth re-established. - Chlorination of both units starting on December 13.
Jan. 2-8, 1973	- Methanol addition to the dentrification chamber at 2:1 ratio - Filamentous bacteria at low levels.
Jan. 9-18, 1973	- Methanol to dentrification chamber at 3:1 ratio - Rising SVI in both units. Filamentous bacteria content increasing.
Jan. 19-Feb. 2, 1973	- Chlorination of both units and recovery period
Feb. 5-12, 1973	- Methanol added to N-removal plant aeration for carbon supplement studies.
Feb. 13-28	- Methanol addition stopped in an attempt to ease bulking sludge conditions in the denitrification clarifier. - Chlorination of both units on the 26th.
March 1-31	- Drop in sludge SVI to below 100 ml/g was achieved in both plants.
Post-aeration on March 1/76	- Ferrous sulphate addition to control aeration. - Improvement of nitrification in both units. - Methanol addition from 12th to 31st.

DATE:	OPERATION AND OBSERVATIONS
April 1-30	- Nitrification in control unit recovered. - N-removal aeration nitrification lagging. - Severe runoff stormwater to plant facility during 1st week. - Methanol addition from 5th to 30th. - Continuous ferrous sulphate addition to control aeration with occasional batch addition to denitrification plant. - SVIs rising in both plants.
May 1-31	- Full nitrification regained in the N-removal plant. - Denitrification regained, particularly with methanol addition. SVIs gradually rose in both plants. - Continuous addition of ferrous sulphate to control plant thoughout month and to the N-removal plant starting May 22, 1976.

APPENDIX B

METEOROLOGICAL DATA

APPENDIX B

METEOROLOGICAL DATA:

SEPTEMBER 1972 to MAY 1973:

MONTH	TEMPERATURE °F		DEGREE DAYS BELOW 65°F		PRECIPITATION INCHES		WATER TEMP. °F	
	MEAN	NORMAL	TOTAL	NORMAL	TOTAL	NORMAL	MAX.	MIN.
September	59.7	60.3	174	186	3.31	3.49	70	62
October	43.3	49.8	667	473	3.90	2.31	62	57
November	33.9	38.1	927	806	2.84	2.40	55	53
December	26.4	25.7	1190	1212	3.74	2.27	52	50
January	24.3	20.6	1255	1369	1.35	2.19	48	43
February	18.3	21.5	1304	1218	1.43	1.95	48	46
March	37.8	30.3	838	1070	4.77	2.36	50	46
April	43.8	43.5	629	641	2.45	2.54	53	46
May	51.6	54.0	408	350	3.46	2.86	57	53
Total	339.1	343.8	7392	7325	27.25	21.37	495	456
Mean	37.67	38.2	82.1	81.4	3.03	2.37	55	50

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Nitrification-denitrification of
wastewater using a single-
sludge system : volume I /
Smith, A. G.

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